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AMERICAN

NOVEMBER 15, 19

Vol. 181—No. 5

Gas Journal

Gas Handbook Issue: 1954

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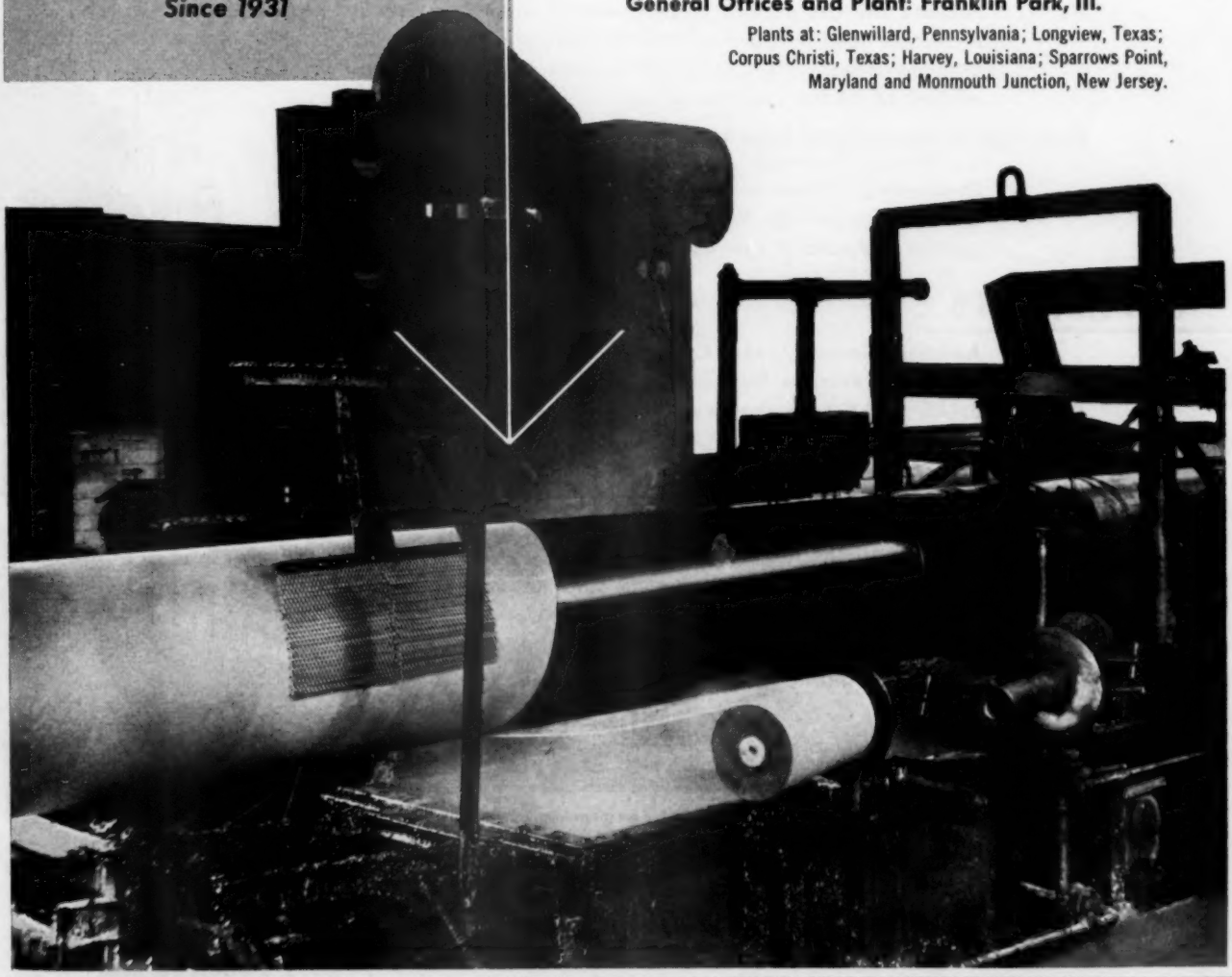

AMERICAN GAS JOURNAL, November 15, 1954. Vol. 181, No. 5. Published monthly (except October, then semi-monthly), by American Gas Journal Inc., at 73 Main Street, Brattleboro, Vt. Application pending for reentry due to change of frequency to monthly (except November, then semi-monthly). Entered as second class matter January 24, 1950, at the post office at Brattleboro, Vt. under Act of March 3, 1879. Executive and editorial offices at 205 East 42nd St., New York 17, New York. Subscription prices, U.S. $3 per year; **Canada $4; Foreign $10. Single copies 50 cents, except November 15 issue, which is** not sold separately. Printed in U.S.A.

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AMERICAN Gas Journal

VOLUME 181 NOVEMBER 15, 1954 NUMBER 5

AMERICAN GAS HANDBOOK ISSUE

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Charles R. Bellamy · Editor of American Gas Handbook Issue

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Arthur Rohman · Western Editor **John F. Falvey · Financial Editor**

AMERICAN GAS JOURNAL, established 1859, is published monthly except October, semi-monthly, by American Gas Journal, Inc., 205 East 42 St., New York 17, N. Y. ROBERT M. POE, President and Treasurer; HILDING H. CARLSON, Vice President; P. M. MALONEY, Secretary.

ADVERTISING REPRESENTATIVES: John P. McDermott, Edwin J. Volckmann, 205 E. 42 St., New York 17, MU 6-4360; Urben Farley & Co., 120 S. LaSalle St., Chicago 3, FI 6-3074; Jack O. Hodges, 479 S. Holt Ave., Los Angeles 48, BR 2-3935; Geo. F. Haines, 681 Market St., San Francisco 5, DO 2-4475.

Member Audit Bureau of Circulations and National Business Publications

Copyright, 1954, American Gas Journal, Inc., New York, N. Y.

Subscription Rates: U.S. $3.00 per year; Canada, $4.00; Foreign, $10.00. Single copies, 50 cents.
November 15 Handbook issue not sold separately.

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DEFINITIONS OF TERMS

Air

AIR is a mixture of nitrogen, oxygen, water vapor, carbon dioxide, argon, neon and small quantities of other rare gases. For all practical purposes of combustion, air may be said to be composed by volume, of—

Oxygen (O_2)—20.9% Nitrogen (N_2)—79.1%

and by weight of

Oxygen (O_2)—23.15% Nitrogen (N_2)—76.85%

WEIGHT OF AIR at 60° F. is .076 lb. per cubic foot at sea level, atmospheric pressure. One pound of air at 60° F. and at atmospheric pressure has a volume of 13.06 cubic feet.

Annealing

ANNEALING is a process involving heating and cooling applied usually to induce softening. The term is also used to cover treatments intended to: (1) Remove stresses, (2) alter mechanical or physical properties, (3) produce a definite microstructure, and (4) remove gases.

Annealing, Bright

BRIGHT ANNEALING is an annealing process which is usually carried out in a controlled furnace atmosphere so that surface oxidation is reduced to a minimum and the surface remains relatively bright.

Atmosphere, Neutral

NEUTRAL ATMOSPHERE in a furnace or heating operation is, as the name suggests, neither oxidizing nor reducing, and indicates a state of perfect combustion. For a given high temperature heating furnace this type of atmosphere is usually the ideal and represents maximum fuel economy in combustion.

Atmosphere, Oxidizing

OXIDIZING ATMOSPHERE in a furnace or heating operation means an atmosphere in which there is an excess of oxygen or air present. Sometimes it is desired to have such an atmosphere to aid certain chemical reactions. In most cases of furnace heating this type of atmosphere results in waste of fuel and scaling of the work. Also, in some cases, an oxidizing atmosphere exists because it has been necessary to reduce the flame temperature by dilution with cold air for low temperature operations.

Atmosphere, Reducing

REDUCING ATMOSPHERE in a furnace or heating operation means an atmosphere in which there is a deficiency of oxygen or air to complete the process of combustion. Such an atmosphere is deliberately produced in some operations to aid certain chemical reactions or to preclude scaling or oxidizing of the work. In most cases of furnace heating excessive reducing atmosphere causes a waste of unconsumed fuel and a lowering of furnace temperature.

British Thermal Unit

THE BRITISH THERMAL UNIT (Btu) is 1/180 of the heat required to raise the temperature of one pound of water from 32° F. to 212° F. Formerly it was defined as the quantity of heat required to raise one pound of water from 62° F. to 63° F. A common nontechnical definition is the amount of heat required to raise the temperature of one pound of water one degree F.

Carburizing

CARBURIZING is a process in which carbon is introduced into a solid iron-base alloy by heating above the transformation temperature range while in contact with a carbonaceous material which may be a solid, liquid, or gas. Carburizing is frequently followed by quenching to produce a hardened case.

Casehardening

CASEHARDENING is a process of surface hardening involving a change in the composition of the outer layer of an iron-base alloy followed by appropriate thermal treatment. Typical caseheardening processes are Carburizing, Cyaniding, Carbonitriding, and Nitriding.

Combustion, Complete

COMPLETE COMBUSTION is the complete oxidation of a fuel regardless of whether or not this is accomplished with an excess amount of oxygen.

Combustion, Perfect

PERFECT COMBUSTION is the complete oxidation of a fuel with exactly the theoretical amount of oxygen required.

Conduction

CONDUCTION is the process of diffusion or flow of heat energy through a mass or body of matter by particle or molecular contact from the warmer to the colder parts. Thus, heat applied to one end of an iron bar will be conducted to the other end from particle to particle within the iron bar.

Convection

CONVECTION is the process of heating a substance by the motion of warmer fluids or gases in contact with the substance. Thus, water tubes in a boiler may be heated by means of the hot products of combustion sweeping over them. The surfaces of the boiler tubes thus heated by convection then *conduct* the heat through the metal of the tubes to the inner surface in contact with the water where the heat is transferred by a combination of conduction and convection to the water.

Cubic Foot, Standard

THE STANDARD CUBIC FOOT is the quantity of gas saturated with water vapor which at a temperature of 60° F. and a pressure of 30 inches of mercury occupies one cubic foot.

This is the standard cubic foot universally used by the manufactured gas industry.

In the natural gas industry, however, gas volumes are usually calculated on a dry basis at a temperature of 60° F. and a specified base pressure.

Degree Day

DEGREE DAY is a term used to express the intensity of the heating season. It is the difference between 65° F. and the daily mean temperature. The sum of these differences for every day of the heating season is the total degree days for the year. Experience has shown that the gas heating season starts when the monthly mean temperature is 65° F., and that gas consumption for house heating is proportional to the drop in temperature below 65° F.

Gas Conditions, Standard

	Manufactured Gas	*Natural Gas*
Gas temperature	60° F.	60° F.
Gas pressure	30 inches of mercury	As per contract
Water vapor in gas	Saturated at 60° F.	Usually dry

Heating Value, Gross

THE GROSS HEATING VALUE of a fuel is the total Btu liberated by complete combustion when the products of combustion are cooled to the temperature of the atmosphere and the water vapor in the products of combustion is condensed to a liquid.

Heating Value, Net

THE NET HEATING VALUE of a fuel is the amount of heat in Btu's which would be available from complete combustion per unit of fuel if the products of combustion were cooled to 212° F. and the water vapor remained as a gas.

THE NET HEATING VALUE of a fuel is equal to the gross heating value minus the latent heat of vaporization of the water vapor present in the products of combustion.

THE NET HEATING VALUE is not determined directly, but is calculated from the gross heating value. The difference between the gross and net heating values is 1122 Btu's per pound of water in the products of combustion. In the case of natural gas, this difference amounts to, roughly, 100 Btu's, while for manufactured gas it is approximately 50 Btu's per cubic foot.

In American gas practice heat standards and appliance efficiencies are based on the gross heating value.

Kilogram Calorie

THE KILOGRAM CALORIE (large calorie) is 1/100 of the heat required to raise the temperature of one kilogram of water from 0° C. to 100° C. A kilogram calorie therefore is equal to 1.8 x 2.2046, or 3.968 Btu's.

Pressure, Absolute

ABSOLUTE PRESSURE is the sum of the gauge pressure and the atmospheric pressure. For example, for gas at 100 lbs. gauge pressure, the absolute pressure at sea level would be 100 + 14.7 = 114.7 lbs.

Load Factor

LOAD FACTOR is the ratio of average daily gas sendout to peak day sendout during a given time interval, usually a year.

Pressure, Atmospheric

ATMOSPHERIC PRESSURE is the pressure at the atmosphere at some definite elevation. At sea level it is 14.7 lbs. per square inch or 760 m.m. (30 inches) of mercury.

Pressure, Critical

CRITICAL PRESSURE is the pressure at which a gas may be liquefied at the critical temperature.

Radiation

RADIATION is the process of heat transmission by heat waves through the air or other gases, an example of which is the sun's rays heating the earth.

Temperature, Absolute

ABSOLUTE TEMPERATURE is the temperature reckoned from the absolute zero.

Temperature, Critical

CRITICAL TEMPERATURE is the temperature above which a gas cannot be liquefied by pressure alone.

Temperature, Ignition

IGNITION TEMPERATURE is the lowest temperature at which a substance can be ignited.

Tempering

TEMPERING is a process of reheating hardened or normalized steel to a temperature below the transformation temperature, range, followed by any desired rate of cooling.

Therm

A THERM is 100,000 Btu's.

Vaporization, Latent Heat of

LATENT HEAT OF VAPORIZATION of a substance is the quantity of heat required to change it from liquid to vapor without raising its temperature.

Zero, Absolute

ABSOLUTE ZERO is the temperature at which a gas would show no pressure if the general law for gases should hold for all temperatures. It is equal to —273.18° C. or —459.72° F.

English Weights and Measures

Length

1000 mils = 1 inch
12 inches = 1 foot
3 feet = 1 yard
5280 feet = 1 mile
4 inches = 1 hand
9 inches = 1 span
2½ feet = 1 pace
16½ feet or 5½ yards = 1 rod
1 knot or nautical mile = 6080.26 feet = 1/3 league
7.92 inches = 1 link
25 links = 1 rod
100 links or 66 feet or 4 rods = 1 chain
10 chains = 1 furlong
8 furlongs = 1 mile

Surface

144 square inches = 1 square foot
9 square feet = 1 square yard
30¼ square yards = 1 square rod
160 square rods = 1 acre
640 acres = 1 square mile
625 square links = 1 square rod
16 square rods = 1 square chain
10 square chains = 1 acre
640 acres = 1 square mile
36 square miles = 1 township

Volume

1728 cubic inches = 1 cubic foot
27 cubic feet = 1 cubic yard
128 cubic feet = 1 cord
24¾ cubic feet = 1 perch

Troy Weight

24 grains (gr.) = 1 pennyweight (dwt.)
20 pennyweights = 1 ounce (oz.)
12 ounces = 1 pound (lb.)

Avoirdupois Weight

16 drams (dr.) = 1 ounce (oz.)
16 ounces = 1 pound (lb.)
25 pounds = 1 quarter (qr.)
4 quarters = 1 hundred weight (cwt.)
20 hundred weight (2000 pounds) = 1 ton (T.)

Apothecaries' Weight

20 grains (gr.) = 1 scruple (sc. or)
3 scruples = 1 dram (dr.or)
8 drams = 1 ounce (oz. or)
12 ounces = 1 pound (lb)

Dry Measure

2 pints (pt.) = 1 quart (qt.)
8 quarts = 1 peck (pk.)
4 pecks = 1 bushel (bu.)
36 bushels = 1 chaldron (ch.)

Liquid Measure

4 gills (gi.) = 1 pint (pt.)
2 pints = 1 quart (qt.)
4 quarts = 1 gallon (gal.)
31½ gallons = 1 barrel (bar.)
63 gallons = 1 hogshead (hhd.)

Apothecaries' Fluid Measure

60 minims = 1 fluid-drachm
8 fluid-drachms = 1 fluid-ounce
16 fluid-ounces = 1 pint
8 pints = 1 gallon

Circular Measure

60 seconds (") = 1 minute (')
60 minutes = 1 degree (°)
30 degrees = 1 sign (s)
12 signs, or 360 degrees = 1 circle (cir.)

THE METRIC SYSTEM

(Extract from tables of equivalents published by the Department of Commerce and Labor, Bureau of Standards.)

The fundamental unit of the metric system is the METER (the unit of length).

From this the units of mass (GRAM) and capacity (LITER) are derived.

All other units are the decimal subdivisions or multiples of these. These three units are simply related, so that for all practical purposes the volume of one kilogram of water (one liter) is equal to one cubic decimeter.

Prefixes	Meaning			Units
Milli-	= one thousandth	$\frac{1}{1000}$	.001	
Centi-	= one hundredth	$\frac{1}{100}$	.01	METER for length
Deci-	= one tenth	$\frac{1}{10}$	.1	
unit	= one		1.	GRAM for mass
Deka-	= ten	$\frac{10}{1}$	10.	
Hecto-	= one hundred	$\frac{100}{1}$	100.	LITER for capacity
Kilo-	= one thousand	$\frac{1000}{1}$	1000.	

The metric terms are formed by combining the words "Meter," "Gram" and "Liter" with the six numerical prefixes.

Length

10 milli-meters (mm)	=	1 centi-meter (cm).
10 centi-meters	=	1 deci-meter (dm).
10 deci-meters	=	1 METER (about 40 inches) (m).
10 meters	=	1 deka-meter (dkm).
10 deka-meters	=	1 hecto-meter (hm).
10 hecto-meters	=	1 kilo-meter (about ⅝ mile) (km).

Mass

10 milli-grams (mg)	=	1 centi-gram (cg).
10 centi-grams	=	1 deci-gram (dg).
10 deci-grams	=	1 GRAM (about 15 grains) (g).
10 grams	=	1 deka-gram (dkg).
10 deka-grams	=	1 hecto-gram (hg).
10 hecto-grams	=	1 kilo-gram (about 2 pounds) (kg).

Capacity

10 milli-liters (ml)	=	1 centi-liter (cl).
10 centi-liters	=	1 deci-liter (dl).
10 deci-liters	=	1 liter (about 1 quart) (1).
10 liters	=	1 deka-liter (dkl).
10 deka-liters	=	1 hecto-liter (about a barrel) (hl).
10 hecto-liters	=	1 kilo-liter (kl).

The square and cubic units are the squares and cubes of the linear units.

The ordinary unit of land area is the Hectare (about 2½ acres).

For ordinary mental comparison it is convenient to know the approximate relations; e.g., 1 meter = 40 inches; 3 decimeters = 1 foot; 1 decimeter = 4 inches; 1 liter = 1 liquid quart; 1 kilogram = 2⅕ pounds; 30 grams = 1 avoirdupois ounce; 1 metric ton = 1 gross ton (see tables).

Equivalents

All lengths, areas and cubic measures in the following tables are derived from the international meter, the legal equivalent being 1 METER = 39.37 INCHES (law of July 28, 1866). In 1893 the United States Office of Standard Weights and Measures was authorized to derive the yard from the meter, using for the purpose the relation legalized in 1866, 1 YARD EQUALS $\frac{3600}{3937}$ METER. The customary weights are likewise referred to the kilogram. (Executive order approved April 5, 1893.) This action fixed the values, inasmuch as the reference standards are as perfect and unalterable as it is possible for human skill to make them.

All capacities are based on the practical equivalent 1 cubic decimeter equals 1 liter. The decimeter is equal to 3.937 inches in accordance with the legal equivalent of the meter given above. The gallon referred to in the tables is the United States gallon of 231 cubic inches. The bushel is the United States bushel of 2150.42 cubic inches. These units must not be confused with the British units of the same name, which differ from those used in the United States. The British gallon is approximately 20 per cent larger, and the British bushel 3 per cent larger, than the corresponding units used in this country.

The customary weights derived from the international kilogram are based on the value 1 avoirdupois pound = 453.5924277 grams. This value is carried out farther than that given in the law, but is in accord with the latter as far as it is there given. The value of the troy pound is based upon the relation just mentioned, and also the equivalent $\frac{5760}{7000}$ avoirdupois pound equals 1 troy pound.

Length

Centimeter	=	0.3937 inch.
Meter	=	3.28 feet.
Meter	=	1.094 yards.
Kilometer	=	0.621 statute mile.
Kilometer	=	0.5396 nautical mile.
Inch	=	2.540 centimeters.
Foot	=	0.305 meter.
Yard	=	0.914 meter.
Statute mile	=	1.61 kilometers.
Nautical mile	=	1.853 kilometers.

Area

Square centimeter	=	0.155 square inch.
Square meter	=	10.76 square feet.
Square meter	=	1.196 square yards.
Hectare	=	2.47 acres.
Square kilometer	=	0.386 square mile.
Square inch	=	6.45 square centimeters.
Square foot	=	0.0929 square meter.
Square yard	=	0.836 square meter.
Acre	=	0.405 hectare.
Square mile	=	2.59 square kilometers.

Volume

Cubic centimeter	=	0.0610 cubic inch.
Cubic meter	=	35.3 cubic feet.
Cubic meter	=	1.308 cubic yards.
Cubic inch	=	16.39 cubic centimeters.
Cubic foot	=	0.0283 cubic meter.
Cubic yard	=	0.765 cubic meter.

Capacity

Milliliter	=	0.0338 U. S. liquid ounce.
Milliliter	=	0.2705 U. S. apothecaries' dram.
Liter	=	1.057 U. S. liquid quarts.
Liter	=	0.2642 U. S. liquid gallon.
Liter	=	0.908 U. S. dry quart.
Dekaliter	=	1.135 U. S. pecks.
Hectoliter	=	2.838 U. S. bushels.
U. S. liquid ounce	=	29.57 milliliters.
U. S. apothecaries' dram	=	3.70 milliliters.
U. S. liquid quart	=	0.946 liter.
U. S. dry quart	=	1.101 liters.
U. S. liquid gallon	=	3.785 liters.
U. S. peck	=	0.881 dekaliter.
U. S. bushel	=	0.3524 hectoliter.

Weight

Gram	=	15.43 grains.
Gram	=	0.772 U. S. apothecaries' scruple.
Gram	=	0.2572 U. S. apothecaries' dram.
Gram	=	0.0353 avoirdupois ounce.
Gram	=	0.03215 troy ounce.
Kilogram	=	2.205 avoirdupois pounds.
Kilogram	=	2.679 troy pounds.
Metric ton	=	0.984 gross or long ton.
Metric ton	=	1.102 short or net tons.
Grain	=	0.0648 gram.
U. S. apothecaries' scruple	=	1.296 grams.
U. S. apothecaries' dram	=	3.89 grams.
Avoirdupois ounce	=	28.35 grams.
Troy ounce	=	31.10 grams.
Avoirdupois pound	=	0.4536 kilogram.
Troy pound	=	0.373 kilogram.
Gross or long ton	=	1.016 metric tons.
Short or net ton	=	0.907 metric ton.

PRESSURE CONVERSION TABLE

	Centimeters of water at 4°C	Inches of water at 4°C	Feet of water at 4°C	Centimeters of mercury	Inches of mercury	Grams per square centimeter	Ounces per square inch	Ounces per square foot	Pounds per square inch	Pounds per square foot	Dynes per square centimeter	Normal atmosphere	45° latitude atmosphere
Centimeters of water at 4°C	1.000000	0.3937000	0.03280833	0.07355393	0.02895818	0.9999730	0.2275682	32.76963	0.01422301	2.048114	980.6385	$0.0_3678148$	$0.0_3678632$
Inches of water at 4°C	2.540005	1.000000	0.08333333	0.1868273	0.07355393	2.539936	0.5780245	83.23552	0.03612653	5.202220	2490.827	$0.0_2458255$	$0.0_2458377$
Feet of water at 4°C	30.48006	12.00000	1.000000	2.241928	0.8826471	30.47924	6.936294	998.8263	0.4335183	62.42664	29889.92	0.02949906	0.02950053
Centimeters of mercury	13.59547	5.352535	0.4460446	1.000000	0.3937000	13.59510	3.093896	445.5211	0.1933685	27.84507	13332.24	0.01315789	0.01315855
Inches of mercury	34.53255	13.59547	1.132956	2.540005	1.000000	34.53162	7.858513	1131.626	0.4911570	70.72661	33863.95	0.03342112	0.03342279
Grams per square centimeter	1.000027	0.3937106	0.03280922	0.07355591	0.02895896	1.000000	0.2275744	32.77071	0.01422340	2.048160	980.6650	$0.0_3678410$	$0.0_3678893$
Ounces per square inch	4.394286	1.730031	0.1441692	0.3232170	0.1272505	4.394168	1.000000	144.0000	0.06250000	9.000000	4309.207	$0.0_4252856$	$0.0_4253068$
Ounces per square foot	0.03051588	0.01201410	0.001001175	0.002244563	$0.0_38836843$	0.03051505	0.006944444	1.000000	$0.0_24340278$	0.06250000	29.92505	$0.0_22953372$	$0.0_22953520$
Pounds per square inch	70.30858	27.68049	2.306707	5.171473	2.036009	70.30669	16.00000	2304.000	1.000000	144.0000	68947.31	0.06804569	0.06804909
Pounds per square foot	0.4882541	0.1922256	0.01601880	0.03591300	0.01413895	0.4882409	0.1111111	16.00000	0.006944444	1.000000	478.8007	$0.0_24725395$	$0.0_24725631$
Dynes per square centimeter	0.001019744	$0.0_24014731$	$0.0_43345609$	$0.0_47500616$	$0.0_42952992$	0.001019716	$0.0_32320613$	0.03341682	$0.0_41450383$	0.002088552	1.000000	$0.0_69869231$	$0.0_69869724$
Normal atmosphere	1033.255	406.7927	33.89939	76.00000	29.92120	1033.228	235.1361	33859.60	14.69601	2116.225	1013250.	1.000000	1.000050
45° latitude atmosphere	1033.204	406.7724	33.89770	75.99620	29.91970	1033.176	235.1244	33857.91	14.69527	2116.119	1013200	0.9999500	1.000000

Expressions like 0.0_3 and 0.0_6 stand for 0.000 and 0.000000.

This table is based on the following values and definitions from I.C.T.:

Standard acceleration of gravity, 980.665 cm per second per second. 1 l = 1000.027 cc, 1 cm = 0.3937 in.

[1] Adapted from *K. C. Testing Lab. Bull.* 25.

45° latitude acceleration of gravity, 980.616 cm per second per second, 1 lb = 453.5924277 g, 1 normal atmosphere = pressure exerted on 1 sq cm by a vertical column of liquid 76 cm in height, of density 13.5951 g per cubic centimeter, at a place where the acceleration of gravity is standard.

45° latitude atmosphere differs from the normal atmosphere only in the value of gravity.

Adapted from "International Critical Table," McGraw-Hill Book Co.
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CONVERSION FACTORS FOR ENERGY UNITS

Acceleration of gravity = 980.665 cm per second per second

Units	Btu	Pcu[2]	Calories (large)	Foot-pounds	Foot-tons	Kilogram-meters	Horsepower-hours	Kilowatt-hours	Joules, inter-national	Pounds carbon[2]	Pounds water[2]
Btu	1.00000	0.555556	0.251983	777.979	0.388990	107.560	$0.0_3392922$	$0.0_4293000$	1,054.46	$0.0_4687569$	0.00103050
Pcu[2]	1.80000	1.00000	0.453569	1,400.36	0.700181	193.607	$0.0_3707260$	$0.0_3527400$	1,898.03	$0.0_3123762$	0.00185490
Calories (large)	3.96852	2.20474	1.00000	3,087.43	1.54372	426.853	0.00155932	0.00116278	4,184.66	$0.0_3272863$	0.00408958
Foot-pounds	0.00128538	$0.0_3714101$	$0.0_3323894$	1.00000	$0.0_3500000$	0.138255	$0.0_5505051$	$0.0_4376617$	1.35539	$0.0_7883788$	$0.0_4132459$
Foot-tons	2.57076	1.42820	0.647788	2,000.00	1.00000	276.510	0.00101010	$0.0_3753233$	2,710.77	$0.0_3176758$	0.00264918
Kilogram-meters	0.00929716	0.00516509	0.00234272	7.23300	0.00361650	1.00000	$0.0_5365306$	$0.0_4272407$	9.80351	$0.0_6639244$	$0.0_4958076$
Horsepower-hours	2,545.03	0.141391	641.304	1,979,980	989.999	273,743	1.00000	0.745694	2,683,640	0.174988	2.62266
Kilowatt-hours	3,412.97	1,896.09	860.009	2,655,220	1,327.61	367,098	1.34103	1.00000	3,598,850	0.234665	3.51707
Joules (international)	$0.0_3948350$	$0.0_3526861$	$0.0_3238968$	0.737797	$0.0_3368898$	0.102004	$0.0_3372628$	$0.0_3277867$	1.00000	$0.0_7652056$	$0.0_4977278$
Pounds carbon[2]	14,544	808.000	3,664.84	11,314,900	5,657.47	1,564,350	5.71466	4.26139	15,336,100	1.00000	14.9876
Pounds water[2]	970.40	539.111	244.524	754,951	377.476	104,376	0.381292	0.284327	1,023,250	0.0667217	1.00000

This table is based upon the following I.C.T. values:

1 Btu (mean)	= 1054.8	absolute joules
1 g-cal (mean)	= 4.186	absolute joules
1 ft-lb	= 1.35582	absolute joules
1 kg-m	= 9.80665	absolute joules
1 hp-hr	= 2.6845×10^6	absolute joules
1 kwhr	= 3.6000×10^6	absolute joules
1 international joule	= 1.00032	absolute joules

[1] Adapted from Van Nostrand's "Chemical Annual" and I.C.T.:

[2] Pcu refers to pound-Centigrade unit. The ton used is 2000 lb. "Pounds carbon" refers to pounds of carbon oxidized to CO_2 of 100 per cent efficiency equivalent to the corresponding number of heat units. "Pounds water" refers to pounds of water evaporated at 212°F at 100 per cent efficiency.

0.0_3 signifies 0.000.

1 cal (small) per gram = 1.8 Btu per pound.

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TEMPERATURE CONVERSION TABLE

°C	0	10	20	30	40	50	60	70	80	90
	F	F	F	F	F	F	F	F	F	F
−200	−328	−346	−364	−382	−400	−418	−436	−454		
−100	−148	−166	−184	−202	−220	−238	−256	−274	−292	−310
−0	+32	+14	−4	−22	−40	−58	−76	−94	−112	−130
0	32	50	68	86	104	122	140	158	176	194
100	212	230	248	266	284	302	320	338	356	374
200	392	410	428	446	464	482	500	518	536	554
300	572	590	608	626	644	662	680	698	716	734
400	752	770	788	806	824	842	860	878	896	914
500	932	950	968	986	1004	1022	1040	1058	1076	1094
600	1112	1130	1148	1166	1184	1202	1220	1238	1256	1274
700	1292	1310	1328	1346	1364	1382	1400	1418	1436	1454
800	1472	1490	1508	1526	1544	1562	1580	1598	1616	1634
900	1652	1670	1688	1706	1724	1742	1760	1778	1796	1814
1000	1832	1850	1868	1886	1904	1922	1940	1958	1976	1994
1100	2012	2030	2048	2066	2084	2102	2120	2138	2156	2174
1200	2192	2210	2228	2246	2264	2282	2300	2318	2336	2354
1300	2372	2390	2408	2426	2444	2462	2480	2498	2516	2534
1400	2552	2570	2588	2606	2624	2642	2660	2678	2696	2714
1500	2732	2750	2768	2786	2804	2822	2840	2858	2876	2894
1600	2912	2930	2948	2966	2984	3002	3020	3038	3056	3074
1700	3092	3110	3128	3146	3164	3182	3200	3218	3236	3254
1800	3272	3290	3308	3326	3344	3362	3380	3398	3416	3434
1900	3452	3470	3488	3506	3524	3542	3560	3578	3596	3614
2000	3632	3650	3668	3686	3704	3722	3740	3758	3776	3794
2100	3812	3830	3848	3866	3884	3902	3920	3938	3956	3974
2200	3992	4010	4028	4046	4064	4082	4100	4118	4136	4154
2300	4172	4190	4208	4226	4244	4262	4280	4298	4316	4334
2400	4352	4370	4388	4406	4424	4442	4460	4478	4496	4514
2500	4532	4550	4568	4586	4604	4622	4640	4658	4676	4694
2600	4712	4730	4748	4766	4784	4802	4820	4838	4856	4874
2700	4892	4910	4928	4946	4964	4982	5000	5018	5036	5054
2800	5072	5090	5108	5126	5144	5162	5180	5198	5216	5234
2900	5252	5270	5288	5306	5324	5342	5360	5378	5396	5414
3000	5432	5450	5468	5486	5504	5522	5540	5558	5576	5594
3100	5612	5630	5648	5666	5684	5702	5720	5738	5756	5774
3200	5792	5810	5828	5846	5864	5882	5900	5918	5936	5954
3300	5972	5990	6008	6026	6044	6062	6080	6098	6116	6134
3400	6152	6170	6188	6206	6224	6242	6260	6278	6296	6314
3500	6332	6350	6368	6386	6404	6422	6440	6458	6476	6494
3600	6512	6530	6548	6566	6584	6602	6620	6638	6656	6674
3700	6692	6710	6728	6746	6764	6782	6800	6818	6836	6854
3800	6872	6890	6908	6926	6944	6962	6980	6998	7016	7034
3900	7052	7070	7088	7106	7124	7142	7160	7178	7196	7214
°C	0	10	20	30	40	50	60	70	80	90

°C	°F
1	1. 8
2	3. 6
3	5. 4
4	7. 2
5	9. 0
6	10. 8
7	12. 6
8	14. 4
9	16. 2
10	18. 0

°F	°C
1	0. 56
2	1. 11
3	1. 67
4	2. 22
5	2. 78
6	3. 33
7	3. 89
8	4. 44
9	5. 00
10	5. 56
11	6. 11
12	6. 67
13	7. 22
14	7. 78
15	8. 33
16	8. 89
17	9. 44
18	10. 00

EXAMPLES: 1347° C = 2444° F + 12.6° F = 2456.6° F. 3367° F = 1850° C + 2.78° C = 1852.78° C.

Bureau of Standards—M126

1 cal (small) per gram = 1.8 Btu per pound.
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FOUR-PLACE LOGARITHM TABLES

No.	0	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396
No.	0	1	2	3	4	5	6	7	8	9

No.	0	1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996
No.	0	1	2	3	4	5	6	7	8	9

$$\text{Log.}\pi = .49715 \quad \text{Log.}_e = 2.302585 \times \text{Log.}_{10}$$

AREAS AND VOLUMES

Square

A = area.

$A = s^2$

$A = \frac{1}{2} d^2$

$s = 0.7071\, d = \sqrt{A}$

$d = 1.414\, s = 1.414 \sqrt{A}$

Rectangle

A = area.

$A = ab$

$d = \sqrt{a^2 + b^2}$

$a = A \div b$

$b = A \div a$

Parallelogram

A = area.

$A = ab$

$a = A \div b$

$b = A \div a$

Note that dimension a is measured at right angles to line b.

Right-angled triangle

A = area.

$A = \frac{bc}{2}$

$A = \sqrt{b^2 + c^2}$

$b = \sqrt{a^2 - c^2}$

$c = \sqrt{a^2 - b^2}$

Acute-angled triangle

A = area.

$A = \frac{bh}{2} = \frac{b}{2}\sqrt{a^2 - \left(\frac{a^2 + b^2 - c^2}{2b}\right)^2}$

Obtuse-angled triangle

A = area.

$A = \frac{bh}{2} = \frac{b}{2}\sqrt{a^2 - \left(\frac{a^2 - b^2 - c^2}{2b}\right)^2}$

Trapezoid

A = area.

$A = \frac{(a + b)\, h}{2}$

Trapezium

A = area.

$A = \frac{(H + h)\, a + bh + cH}{2}$

Regular hexagon

A = area;
R = radius of circumscribed circle;
r = radius of inscribed circle.

$A = 2.598\, s^2 = 2.598\, R^2 = 3.464\, r^2$

$R = s = 1.155\, r$

$r = 0.866\, s = 0.866\, R$

$s = R = 1.155\, r$

Regular octagon

A = area;
R = radius of circumscribed circle;
r = radius of inscribed circle.

$A = 4.828\, s^2 = 2.828\, R^2 = 3.314\, r^2$

$R = 1.307\, s = 1.082\, r$

$r = 1.207\, s = 0.924\, R$

$s = 0.765\, R = 0.828\, r$

Regular polygon

A = area; n = number of sides.

$x = 360° \div n \qquad B = 180° - x$

$A = \frac{nsr}{2} = \frac{ns}{2}\sqrt{R^2 - \frac{s^2}{4}}$

$R = \sqrt{r^2 + \frac{s^2}{4}} \qquad r = \sqrt{R^2 - \frac{s^2}{4}}$

$s = 2\sqrt{R^2 - r^2}$

Circle

A = area; C = circumference.

$A = 0.7854\, d^2$

$C = 3.1416\, d$

$r = C \div 6.2832 = 0.564 \sqrt{A}$

$d = C \div 3.1416 = 1.128 \sqrt{A}$

Circular sector

A = area; l = length of arc;
x = angle, in degrees.

$l = \frac{2A}{r}$

$A = \frac{1}{2} rl$

$x = \frac{57.296\, l}{r} \qquad r = \frac{2A}{l}$

Circular segment

A = area; l = length of arc;
x = angle, in degrees.

$c = 2\sqrt{h(2r - h)}$

$A = \frac{1}{2}[rl - c(r - h)]$

$l = 0.01745\, rx$

$h = r - \frac{1}{2}\sqrt{4r^2 - c^2}$

$x = \frac{57.296\, l}{r}$

Ellipse

A = area;
P = perimeter or circumference.

$A = 3.1416\, ab.$

An approximate formula for the perimeter is:

$P = 3.1416\sqrt{2(a^2 + b^2)}$

Cube

V = volume.

$V = s^3$

Square prism

V = volume.

$V = abc$

$a = \frac{V}{bc} \qquad b = \frac{V}{ac} \qquad c = \frac{V}{ab}$

Prism

V = volume; A = area of end surface.

$V = h \times A$

The area A of the end surface is found by the formulas for areas of plane figures on the preceding pages. Dimension h must be measured perpendicular to end surface.

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(Continued on next page)

AREAS AND VOLUMES *(Continued)*

Pyramid	V = volume. $V = \frac{1}{3} h \times$ area of base.
Frustum of pyramid	V = volume. $V = \frac{h}{3}\left(A_1 + A_2 + \sqrt{A_1 \times A_2}\right)$
Cylinder	V = volume; S = area of curved surface. $V = 0.7854\ d^2h$ $S = 6.2832\ rh$ Area of all surfaces is S plus twice the area of an end.
Portion of cylinder	V = volume; S = area of curved surface. $V = 0.3927\ d^2\ (h_1 + h_2)$ $S = 1.5708\ d\ (h_1 + h_2)$
Hollow cylinder	V = volume. $V = 0.7854\ h\ (D^2 - d^2)$ $= 3.1416\ ht\ (R + r)$
Cone	V = volume; A = area of conical surface. $V = 0.2618\ d^2h$ $A = 1.5708\ ds$ $s = \sqrt{r^2 + h^2}$
Frustum of cone	V = volume; A = area of conical surface. $V = 1.0472\ h\ (R^2 + Rr + r^2)$ $A = 3.1416\ s\ (R + r)$ $a = R - r \qquad s = \sqrt{a^2 + h^2}$
Sphere	V = volume; A = area of surface. $V = 0.5236\ d^3$ $A = 3.1416\ d^2$ $r = 0.6204 \times$ cube root of V
Spherical sector	V = volume; A = total area of conical and spherical surface. $V = 2.0944\ r^2h$ $A = 3.1416\ r\ (2h + \frac{1}{2} c)$ $c = 2\sqrt{h\ (2r - h)}$
Spherical segment	V = volume; A = area of spherical surface. $V = 3.1416\ h^2\left(r - \frac{h}{3}\right)$ $A = 2\pi rh$ $c = 2\sqrt{h\ (2r - h)}$
Spherical zone	V = volume; A = area of spherical surface. $V = 0.5236\ h\left(\frac{3\ c_1^2}{4} + \frac{3\ c_2^2}{4} + h^2\right)$ $A = 2\pi rh = 6.2832\ rh$
Barrel	V = approximate volume. If sides are bent to the arc of a circle: $V = 0.262\ h\ (2\ D^2 + d^2)$ If sides are bent to the arc of a parabola: $V = 0.209\ h\ (2\ D^2 + Dd + \frac{4}{5} d^2)$

GAGE THICKNESS WEIGHT STEEL SHEETS

Gage	Thickness, Inches	Steel	Galvanized Steel
		Weight, Pounds per Square Foot	
7	.1793	7.500	——
8	.1644	6.875	——
9	.1494	6.250	——
10	.1345	5.625	5.7812
11	.1196	5.000	5.1562
12	.1046	4.375	4.5312
13	.0897	3.750	3.9062
14	.0747	3.125	3.2812
15	.0673	2.812	2.9687
16	.0598	2.500	2.6562
17	.0538	2.250	2.4062
18	.0478	2.000	2.1562
19	.0418	1.750	1.9062
20	.0359	1.500	1.6562
21	.0329	1.375	1.5312
22	.0299	1.250	1.4062
23	.0269	1.125	1.2812
24	.0239	1.000	1.1562
25	.0209	.875	1.0312
26	.0179	.750	.9062
27	.0164	.6875	.8437
28	.0149	.625	.7812
29	.0135	.5625	.7187
30	.0120	.500	.6562

CIRCUMFERENCES AND AREAS OF CIRCLES FROM ⅛ TO 20

Diam.	Circum.	Area	Diam.	Circum.	Area
⅛	.3927	.012272	10	31.416	78.54
¼	.7854	.049087	10⅛	31.8087	80.5158
⅜	1.1781	.110447	10¼	32.2014	82.5161
½	1.5708	.19635	10⅜	32.5941	84.5409
⅝	1.9635	.306796	10½	32.9868	86.5903
¾	2.3562	.441787	10⅝	33.3795	88.6643
⅞	2.7489	.601322	10¾	33.7722	90.7628
			10⅞	34.1649	92.8858
1	3.1416	.7854			
1⅛	3.5343	.99402	11	34.5576	95.0334
1¼	3.927	1.2272	11⅛	34.9503	97.2055
1⅜	4.3197	1.4849	11¼	35.343	99.4022
1½	4.7124	1.7671	11⅜	35.7357	101.6234
1⅝	5.1051	2.0739	11½	36.1284	103.8691
1¾	5.4978	2.4053	11⅝	36.5211	106.1394
1⅞	5.8905	2.7612	11¾	36.9138	108.4343
			11⅞	37.3065	110.7537
2	6.2832	3.1416			
2⅛	6.6759	3.5466	12	37.6992	113.098
2¼	7.0686	3.9761	12⅛	38.0919	115.466
2⅜	7.4613	4.4301	12¼	38.4846	117.859
2½	7.854	4.9087	12⅜	38.8773	120.277
2⅝	8.2467	5.4119	12½	39.27	122.719
2¾	8.6394	5.9396	12⅝	39.6627	125.185
2⅞	9.0321	6.4918	12¾	40.0554	127.677
			12⅞	40.4481	130.192
3	9.4248	7.0686			
3⅛	9.8175	7.6699	13	40.8408	132.733
3¼	10.2102	8.2958	13⅛	41.2335	135.297
3⅜	10.6029	8.9462	13¼	41.6262	137.887
3½	10.9956	9.6211	13⅜	42.0189	140.501
3⅝	11.3883	10.3206	13½	42.4116	143.139
3¾	11.781	11.0447	13⅝	42.8043	145.802
3⅞	12.1737	11.7933	13¾	43.197	148.49
			13⅞	43.5897	151.202
4	12.5664	12.5664			
4⅛	12.9591	13.3641	14	43.9824	153.938
4¼	13.3518	14.1863	14⅛	44.3751	156.7
4⅜	13.7445	15.033	14¼	44.7678	159.485
4½	14.1372	15.9043	14⅜	45.1605	162.296
4⅝	14.5299	16.8002	14½	45.5532	165.13
4¾	14.9226	17.7206	14⅝	45.9459	167.99
4⅞	15.3153	18.6655	14¾	46.3386	170.874
			14⅞	46.7313	173.782
5	15.708	19.635			
5⅛	16.1007	20.629	15	47.124	176.715
5¼	16.4934	21.6476	15⅛	47.5167	179.673
5⅜	16.8861	22.6907	15¼	47.9094	182.655
5½	17.2788	23.7583	15⅜	48.3021	185.661
5⅝	17.6715	24.8505	15½	48.6948	188.692
5¾	18.0642	25.9673	15⅝	49.0875	191.748
5⅞	18.4569	27.1086	15¾	49.4802	194.828
			15⅞	49.8729	197.933
6	18.8496	28.2744			
6⅛	19.2423	29.4648	16	50.2656	201.062
6¼	19.635	30.6797	16⅛	50.6583	204.216
6⅜	20.0277	31.9191	16¼	51.051	207.395
6½	20.4204	33.1831	16⅜	51.4437	210.598
6⅝	20.8131	34.4717	16½	51.8364	213.825
6¾	21.2058	35.7848	16⅝	52.2291	217.077
6⅞	21.5985	37.1224	16¾	52.6218	220.354
			16⅞	53.0145	223.655
7	21.9912	38.4846			
7⅛	22.3839	39.8713	17	53 4072	226.981
7¼	22.7766	41.2826	17⅛	53.7999	230.331
7⅜	23.1693	42.7184	17¼	54.1926	233.706
7½	23.562	44.1787	17⅜	54.5853	237.105
7⅝	23.9547	45.6636	17½	54.978	240.529
7¾	24.3474	47.1731	17⅝	55.3707	243.977
7⅞	24.7401	48.7071	17¾	55.7634	247.45
			17⅞	56.1561	250.948
8	25.1328	50.2656			
8⅛	25.5255	51.8487	18	56.5488	254.47
8¼	25.9182	53.4563	18⅛	56.9415	258.016
8⅜	26.3109	55.0884	18¼	57.3342	261.587
8½	26.7036	56.7451	18⅜	57.7269	265.183
8⅝	27.0963	58.4264	18½	58.1196	268.803
8¾	27.489	60.1322	18⅝	58.5123	272.448
8⅞	27.8817	61.8625	18¾	58.905	276.117
			18⅞	59.2977	279.811
9	28.2744	63.6174			
9⅛	28.6671	65.3968	19	59.6904	283.529
9¼	29.0598	67.2008	19⅛	60.0831	287.272
9⅜	29.4525	69.0293	19¼	60.4758	291.04
9½	29.8452	70.8823	19⅜	60.8685	294.832
9⅝	30.2379	72.7599	19½	61.2612	298.648
9¾	30.6306	74.6621	19⅝	61.6539	302.489
9⅞	31.0233	76.5888	19¾	62.0466	306.355
			19⅞	62.4393	310.245
			20	62.832	314.16

NATURAL TRIGONOMETRIC FUNCTIONS

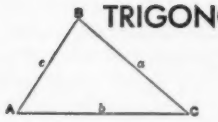
For Angles 0 to 45 Read Down

Degrees	Sines .00° 0′	.25° 15′	.50° 30′	.75° 45′	1.00° 60′	Cosines .00° 0′	.25° 15′	.50° 30′	.75° 45′	1.00° 60′	Degrees
0	0.00000	0.00436	0.00873	0.01309	0.01745	1.00000	0.99999	0.99996	0.99991	0.99985	89
1	0.01745	0.02181	0.02618	0.03054	0.03490	0.99985	0.99976	0.99966	0.99953	0.99939	88
2	0.03490	0.03926	0.04362	0.04798	0.05234	0.99939	0.99923	0.99905	0.99885	0.99863	87
3	0.05234	0.05669	0.06105	0.06540	0.06976	0.99863	0.99839	0.99813	0.99786	0.99756	86
4	0.06976	0.07411	0.07846	0.08281	0.08716	0.99756	0.99725	0.99692	0.99657	0.99619	85
5	0.08716	0.09150	0.09585	0.10019	0.10453	0.99619	0.99580	0.99540	0.99497	0.99452	84
6	0.10453	0.10887	0.11320	0.11754	0.12187	0.99452	0.99406	0.99357	0.99307	0.99255	83
7	0.12187	0.12620	0.13053	0.13485	0.13917	0.99255	0.99200	0.99144	0.99087	0.99027	82
8	0.13917	0.14349	0.14781	0.15212	0.15643	0.99027	0.98965	0.98902	0.98836	0.98769	81
9	0.15643	0.16074	0.16505	0.16935	0.17365	0.98769	0.98700	0.98629	0.98556	0.98481	80
10	0.17365	0.17794	0.18224	0.18652	0.19081	0.98481	0.98404	0.98325	0.98245	0.98163	79
11	0.19081	0.19509	0.19937	0.20364	0.20791	0.98163	0.98079	0.97992	0.97905	0.97815	78
12	0.20791	0.21218	0.21644	0.22070	0.22495	0.97815	0.97723	0.97630	0.97534	0.97437	77
13	0.22495	0.22920	0.23345	0.23769	0.24192	0.97437	0.97338	0.97237	0.97134	0.97030	76
14	0.24192	0.24615	0.25038	0.25460	0.25882	0.97030	0.96923	0.96815	0.96705	0.96593	75
15	0.25882	0.26303	0.26724	0.27144	0.27564	0.96593	0.96479	0.96363	0.96246	0.96126	74
16	0.27564	0.27983	0.28402	0.28820	0.29237	0.96126	0.96005	0.95882	0.95757	0.95630	73
17	0.29237	0.29654	0.30071	0.30486	0.30902	0.95630	0.95502	0.95372	0.95240	0.95106	72
18	0.30902	0.31316	0.31730	0.32144	0.32557	0.95106	0.94970	0.94832	0.94693	0.94552	71
19	0.32557	0.32969	0.33381	0.33792	0.34202	0.94552	0.94409	0.94264	0.94118	0.93969	70
20	0.34202	0.34612	0.35021	0.35429	0.35837	0.93969	0.93819	0.93667	0.93514	0.93358	69
21	0.35837	0.36244	0.36650	0.37056	0.37461	0.93358	0.93201	0.93042	0.92881	0.92718	68
22	0.37461	0.37865	0.38268	0.38671	0.39073	0.92718	0.92554	0.92388	0.92220	0.92050	67
23	0.39073	0.39474	0.39875	0.40275	0.40674	0.92050	0.91879	0.91706	0.91531	0.91355	66
24	0.40674	0.41072	0.41469	0.41866	0.42262	0.91355	0.91176	0.90996	0.90814	0.90631	65
25	0.42262	0.42657	0.43051	0.43445	0.43837	0.90631	0.90446	0.90259	0.90070	0.89879	64
26	0.43837	0.44229	0.44620	0.45010	0.45399	0.89879	0.89687	0.89493	0.89298	0.89101	63
27	0.45399	0.45787	0.46175	0.46561	0.46947	0.89101	0.88902	0.88701	0.88499	0.88295	62
28	0.46947	0.47332	0.47716	0.48099	0.48481	0.88295	0.88089	0.87882	0.87673	0.87462	61
29	0.48481	0.48862	0.49242	0.49622	0.50000	0.87462	0.87250	0.87036	0.86820	0.86603	60
30	0.50000	0.50377	0.50754	0.51129	0.51504	0.86603	0.86384	0.86163	0.85941	0.85717	59
31	0.51504	0.51877	0.52250	0.52621	0.52992	0.85717	0.85491	0.85264	0.85035	0.84805	58
32	0.52992	0.53361	0.53730	0.54097	0.54464	0.84805	0.84573	0.84339	0.84104	0.83867	57
33	0.54464	0.54829	0.55194	0.55557	0.55919	0.83867	0.83629	0.83389	0.83147	0.82904	56
34	0.55919	0.56280	0.56641	0.57000	0.57358	0.82904	0.82659	0.82413	0.82165	0.81915	55
35	0.57358	0.57715	0.58070	0.58425	0.58779	0.81915	0.81664	0.81412	0.81157	0.80902	54
36	0.58779	0.59131	0.59482	0.59832	0.60182	0.80902	0.80644	0.80386	0.80125	0.79864	53
37	0.60182	0.60529	0.60876	0.61222	0.61566	0.79864	0.79600	0.79335	0.79069	0.78801	52
38	0.61566	0.61909	0.62251	0.62592	0.62932	0.78801	0.78532	0.78261	0.77988	0.77715	51
39	0.62932	0.63271	0.63608	0.63944	0.64279	0.77715	0.77439	0.77162	0.76884	0.76604	50
40	0.64279	0.64612	0.64945	0.65276	0.65606	0.76604	0.76323	0.76041	0.75756	0.75471	49
41	0.65606	0.65935	0.66262	0.66588	0.66913	0.75471	0.75184	0.74896	0.74606	0.74314	48
42	0.66913	0.67237	0.67559	0.67880	0.68200	0.74314	0.74022	0.73728	0.73432	0.73135	47
43	0.68200	0.68518	0.68835	0.69151	0.69466	0.73135	0.72837	0.72537	0.72236	0.71934	46
44	0.69466	0.69779	0.70091	0.70401	0.70711	0.71934	0.71630	0.71325	0.71019	0.70711	45
	60′ 1.00°	45′ .75°	30′ .50°	15′ .25°	0′ .00°	60′ 1.00°	45′ .75°	30′ .50°	15′ .25°	0′ .00°	Degrees
	Cosines					Sines					

Degrees	Tangents .00° 0′	.25° 15′	.50° 30′	.75° 45′	1.00° 60′	Cotangents .00° 0′	.25° 15′	.50° 30′	.75° 45′	1.00° 60′	Degrees
0	0.00000	0.00436	0.00873	0.01309	0.01746	Infinity	229.18	114.59	76.390	57.290	89
1	0.01746	0.02182	0.02619	0.03055	0.03492	57.290	45.829	38.188	32.730	28.636	88
2	0.03492	0.03929	0.04366	0.04803	0.05241	28.636	25.452	22.904	20.819	19.081	87
3	0.05241	0.05678	0.06116	0.06554	0.06993	19.081	17.611	16.350	15.257	14.301	86
4	0.06993	0.07431	0.07870	0.08309	0.08749	14.301	13.457	12.706	12.035	11.430	85
5	0.08749	0.09189	0.09629	0.10069	0.10510	11.430	10.883	10.385	9.9310	9.5144	84
6	0.10510	0.10952	0.11394	0.11836	0.12278	9.5144	9.1309	8.7769	8.4490	8.1443	83
7	0.12278	0.12722	0.13165	0.13609	0.14054	8.1443	7.8606	7.5958	7.3479	7.1154	82
8	0.14054	0.14499	0.14945	0.15391	0.15838	7.1154	6.8969	6.6912	6.4971	6.3138	81
9	0.15838	0.16286	0.16734	0.17183	0.17633	6.3138	6.1402	5.9758	5.8197	5.6713	80
10	0.17633	0.18083	0.18534	0.18986	0.19438	5.6713	5.5301	5.3955	5.2672	5.1446	79
11	0.19438	0.19891	0.20345	0.20800	0.21256	5.1446	5.0273	4.9152	4.8077	4.7046	78
12	0.21256	0.21712	0.22169	0.22628	0.23087	4.7046	4.6057	4.5107	4.4194	4.3315	77
13	0.23087	0.23547	0.24008	0.24470	0.24933	4.3315	4.2468	4.1653	4.0867	4.0108	76
14	0.24933	0.25397	0.25862	0.26328	0.26795	4.0108	3.9375	3.8667	3.7983	3.7321	75
15	0.26795	0.27263	0.27732	0.28203	0.28675	3.7321	3.6680	3.6059	3.5457	3.4874	74
16	0.28675	0.29147	0.29621	0.30097	0.30573	3.4874	3.4308	3.3759	3.3226	3.2709	73
17	0.30573	0.31051	0.31530	0.32010	0.32492	3.2709	3.2205	3.1716	3.1240	3.0777	72
18	0.32492	0.32975	0.33460	0.33945	0.34433	3.0777	3.0326	2.9887	2.9459	2.9042	71
19	0.34433	0.34922	0.35412	0.35904	0.36397	2.9042	2.8636	2.8239	2.7852	2.7475	70
20	0.36397	0.36892	0.37388	0.37887	0.38386	2.7475	2.7106	2.6746	2.6395	2.6051	69
21	0.38386	0.38888	0.39391	0.39896	0.40403	2.6051	2.5715	2.5386	2.5065	2.4751	68
22	0.40403	0.40911	0.41421	0.41933	0.42447	2.4751	2.4443	2.4142	2.3847	2.3559	67
23	0.42447	0.42963	0.43481	0.44001	0.44523	2.3559	2.3276	2.2998	2.2727	2.2460	66
24	0.44523	0.45047	0.45573	0.46101	0.46631	2.2460	2.2199	2.1943	2.1692	2.1445	65
25	0.46631	0.47163	0.47698	0.48234	0.48773	2.1445	2.1203	2.0965	2.0732	2.0503	64
26	0.48773	0.49315	0.49858	0.50404	0.50953	2.0503	2.0278	2.0057	1.9840	1.9626	63
27	0.50953	0.51503	0.52057	0.52613	0.53171	1.9626	1.9416	1.9210	1.9007	1.8807	62
28	0.53171	0.53732	0.54296	0.54862	0.55431	1.8807	1.8611	1.8418	1.8228	1.8040	61
29	0.55431	0.56003	0.56577	0.57155	0.57735	1.8040	1.7856	1.7675	1.7496	1.7321	60
30	0.57735	0.58318	0.58905	0.59494	0.60086	1.7321	1.7147	1.6977	1.6808	1.6643	59
31	0.60086	0.60681	0.61280	0.61882	0.62487	1.6643	1.6479	1.6319	1.6160	1.6003	58
32	0.62487	0.63095	0.63707	0.64322	0.64941	1.6003	1.5849	1.5697	1.5547	1.5399	57
33	0.64941	0.65563	0.66189	0.66818	0.67451	1.5399	1.5253	1.5108	1.4966	1.4826	56
34	0.67451	0.68088	0.68728	0.69372	0.70021	1.4826	1.4687	1.4550	1.4415	1.4281	55
35	0.70021	0.70673	0.71329	0.71990	0.72654	1.4281	1.4150	1.4019	1.3891	1.3764	54
36	0.72654	0.73323	0.73996	0.74674	0.75355	1.3764	1.3638	1.3514	1.3392	1.3270	53
37	0.75355	0.76042	0.76733	0.77428	0.78129	1.3270	1.3151	1.3032	1.2915	1.2799	52
38	0.78129	0.78834	0.79544	0.80258	0.80978	1.2799	1.2685	1.2572	1.2460	1.2349	51
39	0.80978	0.81703	0.82434	0.83169	0.83910	1.2349	1.2239	1.2131	1.2024	1.1918	50
40	0.83910	0.84656	0.85408	0.86166	0.86929	1.1918	1.1812	1.1708	1.1606	1.1504	49
41	0.86929	0.87698	0.88473	0.89253	0.90040	1.1504	1.1403	1.1303	1.1204	1.1106	48
42	0.90040	0.90834	0.91633	0.92439	0.93252	1.1106	1.1009	1.0913	1.0818	1.0724	47
43	0.93252	0.94071	0.94896	0.95729	0.96569	1.0724	1.0630	1.0538	1.0446	1.0355	46
44	0.96569	0.97416	0.98270	0.99131	1.00000	1.0355	1.0265	1.0176	1.0088	1.0000	45
	60′ 1.00°	45′ .75°	30′ .50°	15′ .25°	0′ .00°	60′ 1.00°	45′ .75°	30′ .50°	15′ .25°	0′ 00°	Degrees
	Cotangents					Tangents					

For Angles 45 to 90 Read Up

TRIGONOMETRIC FORMULAS



OBLIQUE TRIANGLES

$s = \frac{1}{2}(a+b+c)$

Known	Required	Formulae
A, B, a	C, b	$C = 180° - (A + B)$, $b = \frac{a}{\sin A} \cdot \sin B$
	c	$c = \frac{a}{\sin A} \sin (A + B)$
A, a, b	B, C	$\sin B = \frac{\sin A}{a} \quad b$, $C = 180° - (A + B)$
	c	$c = \frac{a}{\sin A} \cdot \sin C$
C, a, b	$\frac{1}{2}(A + B)$	$\frac{1}{2}(A + B) = 90° - \frac{1}{2} C$
	$\frac{1}{2}(A - B)$	$\tan \frac{1}{2}(A - B) = \frac{a - b}{a + b} \tan \frac{1}{2}(A + B)$
	A, B	$A = \frac{1}{2}(A + B) + \frac{1}{2}(A - B)$ $B = \frac{1}{2}(A + B) - \frac{1}{2}(A - B)$
	c	$c = (a \text{ or } b) \frac{\cos \frac{1}{2}(A + B)}{\cos \frac{1}{2}(A - B)}$ $= (a - b) \frac{\sin \frac{1}{2}(A + B)}{\sin \frac{1}{2}(A - B)}$ $= \sqrt{a^2 + b^2 - 2ab \cdot \cos C}$
	area	area $= \frac{1}{2} a\, b \sin C$.
a, b, c	A	$\sin \frac{1}{2} A = \sqrt{\frac{(s - b)(s - c)}{b\, c}}$
		$\cos \frac{1}{2} A = \sqrt{\frac{s (s - a)}{b\, c}}$
		$\tan \frac{1}{2} A = \sqrt{\frac{(s - b)(s - c)}{s (s - a)}}$
		$\sin A = \frac{2 \sqrt{s (s-a)(s-b)(s-c)}}{b\, c}$
		$\text{vers } A = \frac{2 (s - b)(s - c)}{b\, c}$
	area	area $= \sqrt{s (s - a)(s - b)(s - c)}$
A, B, C, a	area	area $= \frac{a^2 \sin B \cdot \sin C}{2 \sin A}$

COMPOSITION OF AIR

	Dry Air[1]	Percent by Volume Atmospheric Air at Sea Level (Average[2])
Nitrogen	78.03	77.08
Oxygen	20.99	20.75
Argon	.94	.93
Carbon Dioxide	.03	.03
Hydrogen	.01	.01
Water Vapor	—	1.20
Krypton, Neon, Niton, Xenon	Trace	Trace
	100.00	100.00

[1] International Critical Tables.
[2] Guide American Society of Heating and Ventilating Engineers.

MECHANICS OF MATERIALS

Stress is distributed force; its intensity per unit area is generally expressed in pounds per square inch.

The **elastic limit** of a material is the maximum stress in pounds per square inch that will be followed by a complete recovery of form, after the removal of the stress.

Permanent set is the change in form of a member when stressed beyond its elastic limit.

The **ultimate strength** of a material is the least stress in pounds per square inch that will produce rupture.

Modulus of elasticity is the number obtained by dividing the actual stress in pounds per square inch by the corresponding elongation per inch.

The **factor of safety** is the factor obtained by dividing the ultimate strength by the actual stress in pounds per square inch.

Tension and Compression

For direct stress, uniformly distributed,

$$p = \frac{P}{F}$$

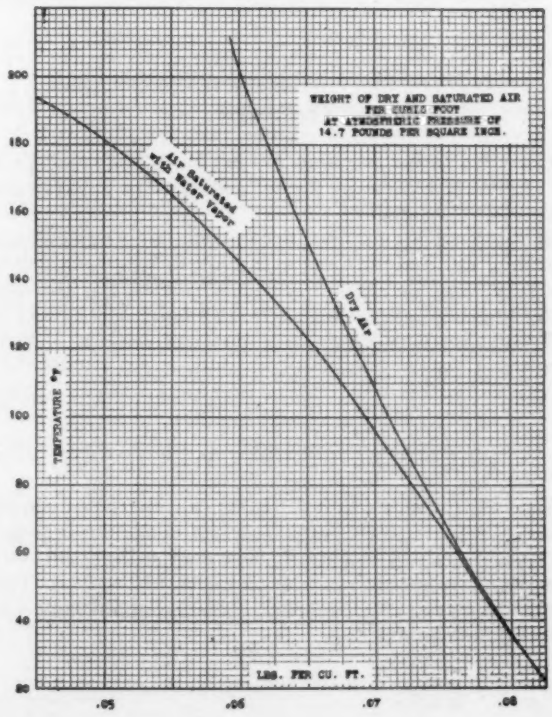
p = stress in pounds per square inch,
P = total load in pounds,
F = cross-sectional area in square inches.

$$E = \frac{p}{\epsilon} \qquad \epsilon = \frac{\lambda}{l}$$

$$E = \frac{\frac{P}{F}}{\frac{\lambda}{l}} = \frac{Pl}{F\lambda}$$

E = modulus of elasticity in tension or compression,
l = length of member in inches,
ϵ = elongation per inch length,
λ = total elongation in inches.

WEIGHT OF DRY AND SATURATED AIR AT DIFFERENT TEMPERATURES IN LBS. PER CU. FT.



DETERMINATION OF HORSEPOWER, TORQUE, ETC.

Horsepower is a unit of mechanical energy or work, and is equal to

33000 ft-lbs per min.
550 ft-lbs per sec.
42.4 Btu per min.

Foot-Pound is a unit of mechanical energy or work, and is the work required to lift one lb. through a vertical distance of one ft.

The Btu (British thermal unit) is equivalent to 778.26 ft. lbs., which is 1/180 part of the heat energy required to raise the temperature of one pound of water from 32° F. to 212° F.

Horsepower-hour is a unit of power, and equals hp. times time in hours of its duration.

Torque is turning effort caused by a force acting normal to a radius at a set distance from the axis of rotation, and is expressed in pound-feet (lbs. at a radius of 1 ft.)—

$$\text{Torque} = \frac{\text{HP}}{\text{RPM}} \times 5250$$

ENGINE HORSEPOWER

Engine horsepower is taken as 33,000 foot-pounds of work in one minute, or 550 foot-pounds of work in one second. To express indicated horsepower the following formula is used:

$$\text{ihp} = \frac{\text{mep LAN}}{33{,}000}$$

Where:

mep is the mean effective pressure (as shown by a steam engine indicator diagram) in pounds per square inch, acting on the piston.
L is the length of the stroke in feet.
A is the area of the piston in square inches (area of the piston rod to be deducted for the crank end).
N is the number of working strokes per minute (in double-acting steam engines it will be twice the number of revolutions).

INDICATED HORSEPOWER OF GAS ENGINES

The same formula is used for this calculation, except that the symbol N represents the total number of explosions per minute in all cylinders.

In computations for four-stroke cycle, single cylinder, single-acting gas engines firing every fourth stroke, this will be the revolutions per minute, divided by two. For two-stroke cycle, single cylinder, single-acting engines, firing every second stroke, or once every revolution, the value of N will be represented by the number of revolutions per minute.

ELECTRICAL HORSEPOWER (INPUT)

The unit for measuring the electrical horsepower input to a motor is the watt. For direct current this is the product of the volts E and the amperes I, measured at the motor terminals, and is represented as $W = EI$. Since 746 watts are equivalent to an electrical horsepower, the following formula represents the above relations:

$$\text{HP} = \frac{EI}{746}$$

Should the power used be taken from an alternating current system, the conditions as outlined below will hold.

If W = watts, E = average volts between terminals, I = average line current, and pf = power factor expressed as a decimal fraction, the following formulae represent their relations:

$$\text{Single phase HP} = \frac{EI \times pf}{746}$$

$$\text{Two phase HP} = \frac{2\,EI \times pf}{746}$$

$$\text{Three phase HP} = \frac{1.732\,EI \times pf}{746}$$

MOTOR SPEED

AC Motors. The synchronous speed of AC motors is determined by the number of poles and frequency.

$$\text{Synchronous speed} = \frac{120 \times \text{f}}{\text{p}}$$

where f = frequency in cycles
p = number of poles of the motor

Induction motors will have full load speeds of from 2 to 6% less than the above, average 4% less.

DC Motors will have standard full-load speeds when hot of: 575, 850, 1150, 1750, and 3500 rev per min (rpm).

At normal temperature, rated load, and voltage the variation above or below the above full-load motor speeds may not exceed 7½% in motors up to 7½ hp at 1150 rpm 5% in motors larger than 7½ hp at 1150 rpm.

ELECTRICAL TERMS

Volt

VOLT is a measure of electrical "pressure" or electro-motive force. Mathematically, it is the product of electrical resistance and electrical current. Volt = Resistance × Current.

Ampere

AMPERE is a practical unit of current and is that current which flows through a conductor having a resistance of 1 ohm and a difference of potential of 1 volt between its ends.

Ohm

OHM is a practical unit of electrical resistance and is that resistance through which the fall of potential is 1 volt when the current strength is 1 ampere.

Watt

WATT is the practical unit of power and is produced when 1 ampere flows under an electromotive force of 1 volt.

Kilowatt Hour

KILOWATT HOUR is the commercial unit of electrical energy and is 1000 watts per hour equivalent to 3412 Btu.

PROPERTIES OF SATURATED STEAM—PRESSURE TABLE

Abs press lb/in²	Temp °F	Specific Volume cu ft per lb		Total Heat Btu per lb		Entropy Btu/°F/lb		Abs press lb/in²
		Sat Liquid	Sat Vapor	Sat Liquid	Sat Vapor	Sat Liquid	Sat Vapor	
14.696	212.00	.01672	26.80	180.07	1150.4	.3120	1.7866	14.696
15	213.03	.01672	26.29	181.11	1150.8	.3135	1.7849	15
20	227.96	.01683	20.089	196.16	1156.3	.3356	1.7519	20
25	240.07	.01692	16.303	208.42	1160.6	.3533	1.7139	25
30	250.33	.01701	13.746	218.82	1164.1	.3680	1.6993	30
35	259.28	.01708	11.898	227.91	1167.1	.3807	1.6870	35
40	267.25	.01715	10.498	236.08	1169.7	.3919	1.6763	40
45	274.44	.01721	9.401	243.36	1172.0	.4019	1.6669	45
50	281.01	.01727	8.515	250.09	1174.1	.4110	1.6585	50
55	287.07	.01732	7.787	256.30	1175.9	.4193	1.6509	55
60	292.71	.01738	7.175	262.09	1177.6	.4270	1.6438	60
65	297.97	.01743	6.658	267.50	1179.1	.4342	1.6374	65
70	302.92	.01748	6.206	272.61	1180.6	.4409	1.6315	70
75	307.60	.01753	5.816	277.45	1181.9	.4472	1.6259	75
80	312.03	.01757	5.472	282.02	1183.1	.4531	1.6207	80
85	316.25	.01761	5.168	286.39	1184.2	.4587	1.6158	85
90	320.27	.01766	4.896	290.56	1185.3	.4641	1.6112	90
95	324.12	.01770	4.652	294.56	1186.2	.4693	1.6068	95
100	327.81	.01774	4.432	298.40	1187.2	.4740	1.6026	100
105	331.36	.01778	4.233	302.10	1188.1	.4787	1.5986	105
110	334.77	.01782	4.049	305.66	1188.9	.4832	1.5948	110
115	338.07	.01785	3.882	309.11	1189.7	.4875	1.5912	115
120	341.25	.01789	3.728	312.44	1190.4	.4916	1.5878	120
125	344.33	.01792	3.587	315.68	1191.1	.4956	1.5844	125
130	347.32	.01796	3.456	318.81	1191.7	.4995	1.5812	130
135	350.21	.01800	3.333	321.85	1192.4	.5032	1.5781	135
140	353.02	.01802	3.220	324.82	1193.0	.5069	1.5751	140
145	355.76	.01806	3.114	327.70	1193.5	.5104	1.5722	145
150	358.43	.01809	3.015	330.51	1194.1	.5138	1.5694	150
155	361.01	.01812	2.922	333.24	1194.6	.5172	1.5666	155
160	363.53	.01815	2.834	335.93	1195.1	.5204	1.5640	160
165	366.00	.01818	2.752	338.54	1195.6	.5235	1.5615	165
170	368.41	.01822	2.675	341.09	1196.0	.5266	1.5590	170
175	370.76	.01825	2.601	343.59	1196.5	.5296	1.5566	175
180	373.06	.01827	2.532	346.03	1196.9	.5325	1.5542	180
185	375.31	.01831	2.466	348.94	1197.3	.5354	1.5518	185
190	377.57	.01833	2.404	350.79	1197.6	.5381	1.5497	190
195	379.67	.01836	2.344	353.10	1198.0	.5409	1.5474	195
200	381.79	.01839	2.288	355.36	1198.4	.5435	1.5453	200
205	383.86	.01842	2.234	357.58	1198.7	.5461	1.5432	205
210	385.90	.01844	2.183	359.77	1199.0	.5487	1.5412	210
215	387.89	.01847	2.134	361.91	1199.3	.5512	1.5392	215
220	389.86	.01850	2.087	364.02	1199.6	.5537	1.5372	220
225	391.79	.01852	2.042	366.09	1199.9	.5561	1.5353	225
230	393.68	.01854	1.999	368.13	1200.1	.5585	1.5334	230

Abs press lb/in²	Temp °F	Specific Volume cu ft per lb		Total Heat Btu per lb		Entropy Btu/°F/lb		Abs press lb/in²
		Sat Liquid	Sat Vapor	Sat Liquid	Sat Vapor	Sat Liquid	Sat. Vapor	
235	395.54	.01857	1.9579	370.14	1200.4	.5608	1.5316	235
240	397.37	.01860	1.9183	372.12	1200.6	.5631	1.5298	240
245	399.16	.01863	1.8803	374.08	1200.9	.5653	1.5280	245
250	400.95	.01865	1.8438	376.00	1201.1	.5675	1.5263	250
260	404.42	.01870	1.7748	379.76	1201.5	.5719	1.5229	260
270	407.78	.01875	1.7107	383.42	1201.9	.5760	1.5196	270
280	411.05	.01880	1.6511	386.98	1202.3	.5801	1.5164	280
290	414.23	.01885	1.5954	390.46	1202.6	.5841	1.5133	290
300	417.33	.01890	1.5433	393.84	1202.8	.5879	1.5104	300
320	423.29	.01899	1.4495	400.39	1203.4	.5953	1.5046	320
340	428.97	.01908	1.3648	406.66	1203.7	.6022	1.4992	340
360	434.40	.01917	1.2885	412.67	1204.1	.6090	1.4941	360
380	439.60	.01925	1.2222	418.45	1204.3	.6153	1.4891	380
400	444.59	.0193	1.1613	424.0	1204.5	.6214	1.4844	400
420	449.39	.0194	1.1061	429.4	1204.6	.6272	1.4799	420
440	454.02	.0195	1.0556	434.6	1204.6	.6329	1.4755	440
460	458.50	.0196	1.0094	439.7	1204.6	.6383	1.4713	460
480	462.82	.0197	.9670	444.6	1204.5	.6436	1.4673	480
500	467.01	.0197	.9278	449.4	1204.4	.6487	1.4634	500
550	476.93	.0199	.8422	460.8	1203.9	.6608	1.4542	550
600	486.21	.0201	.7698	471.6	1203.2	.6720	1.4454	600
650	494.89	.0203	.7084	481.8	1202.3	.6826	1.4373	650
700	503.10	.0205	.6554	491.5	1201.2	.6928	1.4296	700
750	510.85	.0207	.6098	500.8	1199.1	.7019	1.4223	750
800	518.23	.0209	.5687	509.7	1198.6	.7108	1.4153	800
850	525.26	.0210	.5328	518.3	1197.1	.7194	1.4085	850
900	531.98	.0212	.5006	526.6	1195.4	.7278	1.4020	900
950	538.42	.0214	.4717	534.6	1193.6	.7358	1.3957	950
1000	544.61	.0216	.4456	542.4	1191.8	.7430	1.3897	1000
1050	550.57	.0218	.4218	550.0	1189.9	.7504	1.3838	1050
1100	556.31	.0220	.4001	557.4	1187.8	.7578	1.3780	1100
1150	561.86	.0221	.3802	564.6	1185.6	.7644	1.3723	1150
1200	567.22	.0223	.3619	571.7	1183.4	.7711	1.3667	1200
1250	572.42	.0225	.3450	578.6	1181.0	.7776	1.3612	1250
1300	577.46	.0227	.3293	585.4	1178.6	.7840	1.3559	1300
1400	587.10	.0231	.3013	598.7	1173.4	.7963	1.3454	1400
1500	596.23	.0235	.2768	611.6	1167.9	.8082	1.3351	1500
1600	604.90	.0239	.2548	624.1	1162.1	.8196	1.3249	1600
1700	613.15	.0243	.2354	636.3	1156.0	.8306	1.3149	1700
1800	621.03	.0247	.2179	648.3	1149.4	.8412	1.3049	1800
1900	635.82	.0257	.1878	671.7	1138.1	.8619	1.2849	1900
2000	648.13	.0267	.1307	730.6	1091.1	.9136	1.2322	2000
2200	695.36	.0346	.0858	802.8	1020.8	.9731	1.1616	2200
3206.2	705.40	.0503	.0503	902.7	902.7	1.0880	1.0880	3206.2

PROPERTIES OF SUPERHEATED STEAM

Abs Press Lb/in² (Sat temp)	*	Sat Water	Sat Vapor	Temperature—Degrees Fahrenheit						
				300°	400°	500°	600°	700°	800°	900°
1 (101.74)	v	.02	333.6	452.3	512.0	571.6	631.2	690.8	750.4	809.9
	h	69.7	1106.0	1195.8	1241.7	1288.3	1335.7	1383.8	1432.8	1482.5
	s	.1362	1.9782	2.1153	2.1720	2.2233	2.2702	2.3137	2.3542	2.3923
5 (162.24)	v	.02	73.52	90.25	102.36	114.22	126.16	138.10	150.03	161.95
	h	130.1	1131.1	1195.0	1241.2	1288.0	1335.4	1383.6	1432.7	1482.4
	s	.2347	1.8441	1.9370	1.9942	2.0454	2.0927	2.1361	2.1767	2.2148
10 (193.21)	v	.02	38.42	45.00	51.04	57.05	63.03	69.01	74.98	80.95
	h	161.2	1143.3	1193.9	1240.6	1287.5	1335.1	1383.4	1432.5	1482.4
	s	.2835	1.7876	1.8595	1.9172	1.9689	2.0160	2.0596	2.1002	2.1383
14.696 (212.00)	v	.02	26.80	30.53	34.68	38.78	42.86	46.94	51.00	55.07
	h	180.1	1150.4	1192.8	1239.9	1287.1	1334.8	1383.2	1432.3	1482.3
	s	.3120	1.7566	1.8160	1.8743	1.9261	1.9734	2.0170	2.0576	2.0958
20 (227.96)	v	.02	20.09	22.36	25.43	28.46	31.47	34.47	37.46	40.45
	h	196.2	1156.3	1191.6	1239.2	1286.6	1334.4	1382.9	1432.1	1482.1
	s	.3356	1.7319	1.7808	1.8396	1.8918	1.9392	1.9829	2.0235	2.0618
40 (267.25)	v	.017	10.498	11.040	12.625	14.168	15.688	17.198	18.702	20.20
	h	236.0	1169.7	1186.8	1236.5	1284.8	1333.1	1381.9	1431.3	1481.4
	s	.3919	1.6763	1.6994	1.7608	1.8140	1.8619	1.9068	1.9467	1.9850
60 (292.71)	v	.017	7.175	7.259	8.357	9.403	10.427	11.441	12.449	13.452
	h	262.1	1177.6	1181.6	1233.6	1283.0	1331.8	1380.9	1430.5	1480.8
	s	.4270	1.6438	1.6492	1.7135	1.7678	1.8162	1.8608	1.9015	1.9400
80 (312.03)	v	.018	5.472		6.220	7.020	7.797	8.562	9.322	10.077
	h	282.0	1183.1		1230.7	1281.1	1330.5	1379.9	1429.7	1480.1
	s	.4531	1.6207		1.6791	1.7346	1.7836	1.8281	1.8694	1.9079
100 (327.81)	v	.018	4.432		4.937	5.589	6.218	6.835	7.446	8.052
	h	298.4	1187.2		1227.6	1279.1	1329.1	1378.9	1428.9	1479.5
	s	.4740	1.6062		1.6518	1.7085	1.7581	1.8029	1.8443	1.8829
120 (341.25)	v	.018	3.728		4.081	4.636	5.165	5.683	6.195	6.702
	h	312.6	1190.4		1234.4	1277.2	1327.7	1377.8	1428.1	1478.8
	s	.4916	1.5878		1.6287	1.6869	1.7370	1.7822	1.8237	1.8625
140 (353.02)	v	.018	3.220		3.468	3.954	4.413	4.861	5.301	5.738
	h	324.8	1193.0		1221.1	1275.2	1326.4	1376.8	1427.3	1478.2
	s	.5069	1.5751		1.6087	1.6683	1.7190	1.7645	1.8063	1.8451
160 (363.53)	v	.018	2.834		3.008	3.443	3.849	4.244	4.631	5.015
	h	335.9	1195.1		1217.6	1273.1	1325.0	1375.7	1426.4	1477.5
	s	.5204	1.5640		1.5906	1.6519	1.7033	1.7491	1.7911	1.8301
180 (373.06)	v	.018	2.532		2.649	3.044	3.411	3.764	4.110	4.452
	h	346.0	1196.9		1214.0	1271.0	1323.5	1374.7	1425.6	1476.8
	s	.5325	1.5542		1.5745	1.6373	1.6894	1.7355	1.7776	1.8167
200 (381.79)	v	.018	2.288		2.361	2.726	3.060	3.380	3.693	4.002
	h	355.4	1198.4		1210.3	1268.9	1322.1	1373.6	1424.8	1476.2
	s	.5435	1.5453		1.5594	1.6240	1.6767	1.7232	1.7655	1.8048
220 (389.86)	v	.019	2.087		2.125	2.465	2.772	3.066	3.353	3.634
	h	364.0	1199.6		1206.5	1266.7	1320.7	1372.6	1424.0	1475.5
	s	.5537	1.5372		1.5435	1.6117	1.6682	1.7120	1.7545	1.7939
240 (397.37)	v	.0186	1.9183		1.9276	2.247	2.533	2.804	3.068	3.327
	h	372.1	1200.6		1202.5	1264.5	1319.2	1371.5	1423.2	1474.8
	s	.5631	1.5298		1.5319	1.6003	1.6546	1.7017	1.7444	1.7839
260 (404.42)	v	.0187	1.7748			2.063	2.330	2.582	2.827	3.067
	h	379.8	1201.5			1262.2	1317.7	1370.4	1422.3	1474.2
	s	.5719	1.5229			1.5897	1.6447	1.6922	1.7352	1.7748

lbs Press Lb/in² (Sat temp)		Sat Water	Sat Vapor	Temperature—Degrees Fahrenheit					
				600°	700°	800°	900°	1000°	1200°	1400°
280 (411.05)	v	.0188	1.6511	2.156	2.392	2.621	2.845	3.066	3.501	3.928
	h	387.0	1202.3	1316.2	1369.4	1421.5	1473.5	1525.8	1632.1	1741.4
	s	.5801	1.5164	1.6354	1.6834	1.7265	1.7662	1.8033	1.8716	1.9337
300 (417.33)	v	.0199	1.5433	2.005	2.227	2.442	2.652	2.859	3.269	3.674
	h	393.8	1202.8	1314.7	1368.3	1420.6	1472.8	1525.2	1631.7	1741.0
	s	.5879	1.5104	1.6268	1.6751	1.7184	1.7582	1.7954	1.8638	1.9260
350 (431.72)	v	.0191	1.3260	1.7036	1.8980	2.084	2.266	2.445	2.798	3.147
	h	409.7	1203.9	1310.9	1365.5	1418.5	1471.1	1523.8	1630.7	1740.3
	s	.6066	1.4966	1.6070	1.6563	1.7002	1.7408	1.7777	1.8463	1.9086
400 (444.59)	v	.0193	1.1613	1.4770	1.6508	1.8161	1.9767	2.134	2.445	2.751
	h	424.0	1204.5	1306.9	1362.7	1416.4	1469.4	1522.4	1629.6	1739.5
	s	.6214	1.4844	1.5894	1.6398	1.6842	1.7247	1.7623	1.8311	1.8936
500 (467.01)	v	.0197	.9278	1.1591	1.3044	1.4405	1.5715	1.6996	1.9504	2.197
	h	449.4	1204.4	1298.6	1357.0	1412.1	1466.0	1519.6	1627.6	1737.9
	s	.6487	1.4624	1.5568	1.6115	1.6571	1.6982	1.7363	1.8064	1.8683
600 (486.21)	v	.0201	.7698	.9463	1.0732	1.1899	1.3013	1.4096	1.6208	1.8279
	h	471.6	1203.2	1289.9	1351.1	1407.7	1462.5	1516.7	1625.5	1736.2
	s	.6720	1.4454	1.5323	1.5875	1.6343	1.6762	1.7147	1.7866	1.8496
700 (503.10)	v	.0205	.6554	.7934	.9077	1.0108	1.1082	1.2024	1.3853	1.5641
	h	491.5	1201.2	1280.6	1345.0	1403.2	1459.0	1513.9	1623.5	1734.8
	s	.6925	1.4296	1.5084	1.5665	1.6147	1.6573	1.6963	1.7666	1.8299
800 (518.23)	v	.0209	.5687	.6779	.7833	.8763	.9633	1.0470	1.2068	1.3662
	h	509.7	1198.6	1270.7	1338.6	1398.6	1455.4	1511.0	1621.4	1733.2
	s	.7106	1.4153	1.4863	1.5476	1.5972	1.6407	1.6801	1.7510	1.8146
900 (531.98)	v	.0216	.4456	.5840	.6884	.6878	.7604	.8294	.9615	1.0893
	h	542.4	1191.8	1348.8	1325.3	1389.2	1448.2	1505.1	1617.3	1730.0
	s	.7430	1.3897	1.4650	1.5161	1.5670	1.6121	1.6525	1.7265	1.7896
1000 (544.61)	v	.0223	.3619	.4016	.4909	.3617	.6250	.6843	.7967	.9046
	h	571.7	1183.4	1223.5	1311.0	1379.3	1440.7	1499.2	1613.1	1726.9
	s	.7711	1.3667	1.4062	1.4843	1.5409	1.5879	1.6293	1.7025	1.7672
1100 (567.22)	v	.0231	.3012	.3174	.4062	.4714	.5281	.5805	.6799	.7727
	h	598.7	1173.4	1193.0	1295.5	1369.1	1433.1	1493.2	1608.9	1723.7
	s	.7963	1.3454	1.3639	1.4567	1.5177	1.5666	1.6093	1.6836	1.7489
1200 (587.10)	v	.0239	.2548		.3417	.4034	.4553	.5027	.5906	.6738
	h	624.1	1162.1		1279.7	1358.4	1425.3	1487.0	1604.6	1720.5
	s	.8196	1.3249		1.4303	1.4964	1.5476	1.5916	1.6669	1.7328
1300 (621.03)	v	.0247	.2179		.2907	.3505	.3986	.4421	.5218	.5968
	h	648.3	1149.4		1260.3	1347.2	1417.4	1480.8	1600.4	1717.3
	s	.8412	1.3049		1.4044	1.4765	1.5301	1.5752	1.6520	1.7188
1400 (635.82)	v	.0257	.1878		.2489	.3074	.3532	.3935	.4668	.5352
	h	671.7	1138.1		1240.0	1335.5	1409.2	1474.5	1596.1	1716.1
	s	.8619	1.2849		1.3783	1.4576	1.5139	1.5603	1.6384	1.7065

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*v—Specific volume in cu ft/lb h—Total heat in Btu/lb s—Entropy in Btu/°F/lb

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BOILER HORSEPOWER

The equivalent evaporation of 34.5 pounds of water per hour from a feed water temperature of 212 deg F. into steam at the same temperature is a boiler horsepower. Since the actual operating conditions of a boiler are seldom "from and at 212 deg F" a factor is needed to convert the rating from the actual conditions to what they would be "from and at 212 deg." This is called the "factor of evaporation" and equals ratio of the heat required to generate 1 pound of steam under actual conditions to that required to make 1 pound of steam "from and at 212 deg F."

NOTES ON STEAM AND STEAM BOILERS

Steam is perfectly transparent, colorless, dry, and invisible. When partially condensed, as in contact with the air, the mist or spray makes it visible.

Dry steam contains no free moisture. It may be either saturated or superheated.

Wet steam contains free moisture in the form of mist or spray, and has the same temperature as dry saturated steam at the same pressure.

Saturated steam is steam in its normal state. Its temperature is that due to the pressure under which it is formed; that is its temperature is the same as that of the water from which it is generated and upon which it rests.

Superheated steam is steam at a temperature above that due to its pressure being further heated from another source, after leaving the water from which it is generated.

One volume of water evaporated at normal atmospheric pressure and temperature of 212° F. becomes 1603 volumes of steam.

One cu. ft. of steam weighs .03731 lbs., and 1 lb. of steam occupies 26.80 cu. ft., at a pressure of 14.696 lbs. per square inch and a temperature at 212° F.

The latent heat of vaporization of water to steam is 970.3 Btu per lb. at atmospheric pressure.

The best designed boilers, well set, with good draft and skillful firing, will evaporate from 7 to 10 lbs. of water per pound of first-class coal.

With small boilers in industrial plants, heat liberations of approximately 15,000 Btu per cu. ft. of furnace volume per hour are attained, whereas, in large central stations, this can run up to 30,000 Btu per cu. ft. or higher.

The horsepower rating of a boiler is based on its heating surface, 10 square feet of heating surface being allowed per rated horsepower.

The relation between heat liberation, heating surface, per cent rating, and boiler efficiency is as follows:

$$\text{Heat liberation Btu per hr.} = \frac{\text{Heating Surface} \times 33{,}500 \times \%\ \text{Rating}}{10 \times \%\ \text{efficiency}}$$

The information on horsepower calculations, motors, steam and steam boilers is published through courtesy of "Compressed Air Data" and "Cameron Pump Data."

WATER HORSEPOWER FORMULAS

$$\text{Water H.P.} = \frac{\text{gal. per min.} \times \text{head in feet} \times \text{specific gravity}}{3960}$$

$$\text{or Water H.P.} = \frac{\text{gal. per min.} \times \text{head in lbs. per sq. in.}}{1714}$$

$$\text{Brake H.P.} = \frac{\text{Water H.P.}}{\text{Efficiency of Pump}}$$

$$\text{Kw. hrs. per 1,000 gal. cold water pumped per hour} = \frac{\text{head in feet of water} \times 0.00315}{\text{efficiency of pump} \times \text{efficiency of motor}}$$

Cameron Hydraulic Data.

EFFICIENCIES OF ELECTRIC MOTORS

Average Efficiencies for Voltages up to 550 in Three Phase Motors

Rating	Induction Motors			Unity P. F. Syn. Motors		
	Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load
1 to 2 Hp.	81	79	76			
3 to 5 Hp.	85	84	82			
10 to 25 Hp.	87.5	87	85			
25 to 50 Hp.	89	88.5	86.5	90	88.5	85
75 Hp.-100 Hp.	91	90	88	92	91	88
150-200 Hp.	92	91.5	89.5	93	92	89.5
Above 200 Hp.	93.5	93	91	94.5	93.5	92

The above are averages for 1200 and 1800 RPM motors.
Low speed motors.—Efficiencies will be from 1 to 2% lower—2200 volt motors 100 HP and above have approximately the same efficiency as low voltage motors. On smaller sizes the 2200 volt motors have efficiencies 1 to 2% lower.
Slip ring motors in the smaller sizes will have full load efficiencies of 1 to 3% o wer.

POWER REQUIREMENTS OF POSITIVE BLOWERS AND EXHAUSTERS

$$\text{B.H.P.} = .00474 \times \text{D} \times \text{R.P.M.} \times \text{P.}$$

Where

B.H.P. equals horsepower required to drive the blower or exhauster.

D equals displacement in cubic feet per revolution.

R.P.M. equals revolutions per minute.

P equals outlet minus inlet pressure in pounds per square inch. (If inlet pressure is atmospheric, then P is the outlet gauge pressure.)

Note: This formula assumes a mechanical efficiency of 92 per cent for the blower or exhauster.

Volumetric efficiency is provided for since actual capacity is less than actual R.P.M. multiplied by displacement.

Engineering Tables—Roots-Connersville.

BEARING POWER OF SOILS

Bearing Power in Tons Per Square Foot

Minimum	Maximum	Type of Soil
200		Rock in thick layers—native.
25	30	Rock equal to best ashler masonry.
15	20	Rock equal to best brick masonry.
5	10	Rock equal to poor brick masonry.
4	6	Clay in thick beds always dry.
2	4	Clay in thick bed moderately dry.
1	2	Clay soft.
8	10	Gravel and coarse sand well cemented.
4	6	Sand compact and well cemented.
2	4	Sand clean and dry.
0.5	1	Quick sand and alluvial soils.

TABLE OF SUGGESTED CONCRETE MIXTURES

TYPE OF WORK	Gallons of Water Per Bag of Cement	Trial Mix
Structural parts, columns, etc., subjected to high stresses	5	1-1¾-2¾
Sea water concrete	4	1-1¾-2¾
Reinforced slabs	5	1-2-3
Concrete subjected to water pressure such as: Swimming pools, Reservoirs, Cisterns, Elevator pits, Vats, etc.	4½	1-2-3
Fence posts and other pre-cast units	5	1-2-3
Reinforced concrete such as: Walls, Columns, Girders, Beams	5½	1-2-3½
Retaining Walls	5	1-2-3½
Septic Tanks	5½	1-2-3½
Curbs, Driveways and Approaches	4½	1-2-3½
Engine foundations, heavily loaded and subjected to vibration	4½	1-2-3½
Sidewalks, Steps and Stairways	5½	1-2½-4
Silos, Grain and Coal Bins, and similar structures	5½	1-2½-4
Manure Pits, Dipping Vats, Hog Wallows	6	1-2½-4
Gutters, Runways, Hotbeds, etc.	5½	1-2½-4
Basement walls not subject to water pressure	6	1-2½-4
Footings, Foundations	6½	1-3 5
Heavy retaining walls	6	1-3-5
Engine foundations not subject to excessive vibration	6	1-3-5
Barnyard pavements and feeding floors	5½	1-3-5

Note:—Suggested water per bag of cement makes allowance for average moisture in aggregates as used. If the aggregates are wet the recommended water should be reduced 1 gallon per bag.

Do not adjust the water content to the mix. If the trial batch proves too stiff, reduce the amount of sand and stone until the desired consistency is obtained.

MATERIALS REQUIRED FOR 1 CUBIC YARD OF MORTAR AND CONCRETE

Mixture	¾" Gravel			1" Stone Dust Out			2½" Stone Dust Out			2½" Stone Most Small Stone Out		
	Barrels Cement	Cubic Yard Sand	Cubic Yard Stone	Barrels Cement	Cubic Yard Sand	Cubic Yard Stone	Barrels Cement	Cubic Yard Sand	Cubic Yard Stone	Barrels Cement	Cubic Yard Sand	Cubic Yard Stone
Mortar												
1:1½	3.61	0.80	Using	very	fine	sand	3.87	0.86		Using	coarse	sand
1:2	3.02	0.90	"	"	"	"	3.21	0.95		"	"	"
1:2½	2.60	0.96	"	"	"	"	2.74	1.01		"	"	"
1:3	2.28	1.01	"	"	"	"	2.39	1.06		"	"	"
Concrete												
1:1:2	2.30	0.35	0.74	2.57	0.39	0.78	2.63	0.40	0.80	2.72	0.41	0.83
1:1½:3	1.71	0.39	0.78	1.85	0.42	0.84	1.90	0.43	0.87	1.96	0.45	0.89
1:1¾:2¾	1.75	0.43	0.75	1.85	0.47	0.80	1.93	0.46	0.84	2.00	0.48	0.85
1:2:3	1.54	0.47	0.73	1.70	0.52	0.77	1.73	0.53	0.79	1.78	0.54	0.81
1:2:3½	1.44	0.44	0.77	1.57	0.48	0.83	1.61	0.49	0.85	1.66	0.50	0.88
1:2:4	1.34	0.41	0.81	1.46	0.44	0.89	1.48	0.45	0.90	1.53	0.47	0.93
1:2½:4	1.24	0.47	0.75	1.35	0.52	0.82	1.38	0.53	0.84	1.42	0.54	0.87
1:2½:4½	1.16	0.44	0.80	1.27	0.48	0.87	1.29	0.49	0.88	1.33	0.51	0.91
1:2½:5	1.10	0.42	0.83	1.19	0.46	0.91	1.21	0.46	0.92	1.26	0.48	0.96
1:3:4	1.15	0.52	0.72	1.26	0.58	0.77	1.28	0.58	0.78	1.32	0.60	0.80
1:3:5	1.03	0.47	0.78	1.11	0.51	0.85	1.14	0.52	0.87	1.17	0.54	0.89
1:3:6	0.92	0.42	0.84	1.01	0.46	0.92	1.02	0.47	0.93	1.06	0.48	0.97

WATER CEMENT RATIOS

Water cement ratio means the relation of water in volume to cement in volume as used to make concrete. For example, if the amount of water in the batch is 1 cubic foot (7½ gallons) and the amount of cement in the batch is also 1 cubic foot (1 sack) then the W/C ratio is 1.0. If the water content is 7 gallons per sack of cement, then the W/C will be $\frac{7}{7.5} = 0.933$ or 0.933 cu. feet of water per batch.

Water Cement Ratio by Volume	Gal. Water Per Sack of Cement	Lb. Water Per Sack of Cement	Lb. Water Per 10 lb. Cement
.53	4.0	33.2	3.53
.59	4.5	37.35	3.97
.66	5.0	41.5	4.41
.73	5.5	45.65	4.85
.80	6.0	49.8	5.29
.86	6.5	53.95	5.73
.93	7.0	58.1	6.17
1.00	7.5	62.5	6.61
1.06	8.0	66.4	7.05

94 lbs. cement = 1 sack
1 sack cement = 1 cu. ft.
7½ gals. water = 1 cu. ft.
62½ lbs. water = 1 cu. ft.
8⅓ lbs. water = 1 gallon

By "water" is meant water in the sand and stone plus that added at the mixer.

Very wet sand will contain from ¾ to 1 gallon per cubic foot.

Moderately wet sand will contain about ½ gallon per cubic foot.

Moist sand will contain about ¼ gallon per cubic foot.

NOTE: THE COARSER THE SAND, THE LESS WATER IT WILL CARRY.

Lehigh Portland Cement Co.

PHYSICAL CONSTANTS OF CHEMICAL ELEMENTS

Element	Symbol	Atomic Weight 1941	Specific Gravity 68°F.(1)	Melting Point °F.	Boiling Point °F.	Specific Heat at 68°F.	Coef. Linear Thermal Expansion per °F. at 65°F. ×10⁶(3)
Aluminum	Al	26.97	2.702	1218	3270	.214	12.8
Antimony	Sb	121.76	6.684	1165	2520	.050	6.3
Argon, gas	A	39.944	1.379	....	....	.125	....
liquid	A	39.944	1.42 (2)	—309	—302	.134 (8)	....
Arsenic, am.	As	74.91	3.70	....	....	.086 (6)	2.6
cryst.	As	74.91	5.727	(5)	1139	.082 (6)	2.6
Barium	Ba	137.36	3.5	1560	2080	.068	....
Beryllium	Be	9.02	1.85	2460	2787	.397	6.8 (9)
Bismuth	Bi	209.00	9.80	520	2640	.029	7.4
Boron	B	10.82	2.3	4200	4600	.309	....
Bromine, gas	Br	79.916	5.87 (2)	....	....	.055 (2)	....
liquid	Br	79.916	2.928	19	138	.107	....
Cadmium	Cd	112.41	8.642	610	1413	.055	16.6
Calcium	Ca	40.08	1.55	1490	2620	.155	14.0
Carbon, am.	C	12.010	1.90	6380	7600	.204	3.0
graphite	C	12.010	2.25	6380	7600	.168	4.4
diamond	C	12.010	3.52	6380	7600	.117	0.7
Cerium	Ce	140.13	6.91	1180	2550	.042 (6)	....
Cesium	Cs	132.91	1.90	83	1240	.052	54.0
Chlorine, gas	Cl	35.457	2.486	....	....	.115	....
liquid	Cl	35.457	1.557 (2)	—152	—29	.226 (2)	....
Chromium	Cr	52.01	6.92	2940	4000	.110	3.3 (4)
Cobalt	Co	58.94	8.71	2700	5250	.100	6.8
Columbium	Cb	92.91	8.4	3540	5250	...	4.0
Copper	Cu	63.57	8.92	1981	4190	.092	9.2
Dysprosium	Dy	162.46	....	....	....	...	....
Erbium	Er	167.2	4.77	....	....	...	....
Europium	Eu	152.0	....	....	....	...	....
Fluorine, gas	F	19.00	1.312	....	....	.182	....
liquid	F	19.00	1.108 (2)	—369	—305	...	....
Gadolinium	Gd	156.9	1.31	....	....	...	....
Gallium	Ga	69.72	5.903	86	3600	.079	10.0
Germanium	Ge	72.60	5.35	1757	4900	.074 (6)	9.3
Gold	Au	197.2	19.32	1945	4700	.031	7.9
Hafnium	Hf	178.6	13.3	4000	5800	...	....
Helium, gas	He	4.003	.138	—458	—452	1.25	....
Holmium	Ho	164.94	....	....	....	...	....
Hydrogen, gas	H	1.0080	.06952	....	....	3.391	....
liquid	H	1.0080	.071 (2)	—435	—423	.231 (2)	....
Indium	In	114.76	7.31	311	2640	.057 (6)	23.2
Iodine, gas	I	126.92	8.72 (2)	....	....	.034 (2)	....
solid	I	126.92	4.93	237	361	.052	52.0
Iridium	Ir	193.1	22.42	4420	8000	.031	3.6
Iron, pure	Fe	55.85	7.865	2795	5400	.107	6.5
wrought	Fe	55.85	7.78	2750	....	.111	6.8
gray steel	Fe	55.85	7.86	2680	....	.115	6.9
cast	Fe	55.85	7.1	2245	....	.115	5.8
Krypton, gas	Kr	83.7	2.868	....	....	...	....
liquid	Kr	83.7	2.16 (2)	—251	—243	...	....
Lanthanum	La	138.92	6.15	1519	3300	.045 (6)	....
Lead	Pb	207.21	11.344	621	2935	.031	15.9
Lithium	Li	6.940	.534	367	2437	.830	31.0
Lutecium	Lu	174.99	....	....	....	...	....
Magnesium	Mg	24.32	1.74	1204	2030	.246	14.0
Manganese	Mn	54.93	7.20	2300	3450	.121 (9)	13.0
Mercury, liquid	Hg	200.61	13.546	—38	674	.03325	101.0 (7)
Molybdenum	Mo	95.95	10.2	4750	6700	.065 (9)	2.7 (9)
Neodymium	Nd	144.27	6.9	1540	....	.045 (6)	....
Neon, gas	Ne	20.183	.696	—416	—411	...	....
Nickel	Ni	58.69	8.90	2646	5250	.105	7.1
Nitrogen, gas	N	14.008	.9673	....	....	.2477	....
liquid	N	14.008	.808 (2)	—346	—320	.474 (2)	....
Osmium	Os	190.2	22.48	4900	>9550	.031 (9)	3.4
Oxygen, gas	O	16.0000	1.1053	....	....	.2178	....
liquid	O	16.0000	1.14 (2)	—361	—297	.394 (2)	....
Ozone, gas	O_3	....	1.658	—420	—170	...	....
Palladium	Pd	106.7	11.97	2830	>4000	.055	6.5
Phosphorus, yellow	P	30.98	1.82	111	....	.189	69.0
red	P	30.98	2.20	1094 at 43 atm.	....	.190	....
liquid	P	30.98	1.745 (8)	....	536	...	....
Platinum	Pt	195.23	21.45	3224	7770	.032	5.0
Potassium	K	39.096	.86	144	1400	.184	46.0
Praseodymium	Pr	140.92	6.5	1725	....	.046 (6)	....
Protactinium	Pa	231	....	5430	....	...	....
Radium	Ra	226.05	5.0	1760	2080	...	....
Radon, gas	Rn	222	7.526	....	....	...	....
solid	Rn	222	4.0 (8)	—96	—79	...	....
Rhenium	Re	186.31	20.53	6220	....	.033	....
Rhodium	Rh	102.91	12.5	3600	>4500	.059	4.7
Rubidium	Rb	85.48	1.532	101	1290	.080	48.0
Ruthenium	Ru	101.7	12.063	4440	7500	.061 (6)	5.1
Samarium	Sm	150.43	7.7	>2370	....	...	....
Scandium	Sc	45.10	2.5	2200	4350	...	....
Selenium, gray	Se	78.96	4.79	423	1270	.077	20.4
red	Se	78.96	4.46	....	1270	...	....
Silicon	Si	28.06	2.4	2590	4700	.173	4.1
Silver	Ag	107.880	10.5	1761	3540	.056	10.5
Sodium	Na	22.997	.971	208	1616	.295	39.0
Strontium	Sr	87.63	2.6	1386	2100	.074	....
Sulphur, rhombic	S	32.06	2.07	235	832	.173	36.0
monoclinic	S	32.06	1.96	246	832	.181	36.0
amorphous	S	32.06	1.92	>250	832	...	36.0
Tantalum	Ta	180.88	16.6	5160	>7400	.036	3.7
Tellurium, amorphous	Te	127.61	6.00	846	2535	.053	9.3
cryst.	Te	127.61	6.25	846	2535	.048	9.3
Terbium	Tb	159.2	....	621	....	.048	....
Thallium	Tl	204.39	11.85	578	3000	.031	16.8
Thorium	Th	232.12	11.2	3350	>5400	.028 (6)	6.2 (4)
Thulium	Tm	169.4	....	....	....	...	....
Tin, gray	Sn	118.70	5.75	449	4120	.052	....
rhombic	Sn	118.70	6.53	449	4120	...	....
tetrahedral	Sn	118.70	7.28	449	4120	.054	13.7
Titanium	Ti	47.90	4.5	3270	>5400	.100	....
Tungsten	W	183.92	19.3	6100	10650	.031	2.4
Uranium	U	238.07	18.7	>3360	....	.028 (6)	....
Vanadium	V	50.95	5.866	3120	5430	.115 (6)	....
Xenon, gas	Xe	131.3	4.525	....	....	...	....
liquid	Xe	131.3	3.06 (2)	—170	—161	...	....
Ytterbium	Yb	173.04	....	3270	....	...	....
Yttrium	Y	88.92	5.51	2700	4530	...	....
Zinc	Zn	65.38	7.14	787	1665	.092	16.5
Zirconium	Zr	91.22	6.4	3450	>5250	.066	....

(1) Specific Gravity.—the density of the element at 68° F. (20° C.) has been compared to that of water at 60° F. in the case of liquids and solids (unless otherwise noted). The density of gases has been compared to that of air.
(2) At boiling point.
(3) 10^6 means that for convenience the coefficients of linear expansion have been multiplied by 1,000,000 to obtain the figures shown in the table. In using move the decimal point 6 places to the left. Thus the coefficient of linear thermal expansion for Aluminum is .0000128.
(4) 68° to 140° F.
(5) Sublimes.
(6) 32° to 212° F.
(7) Cubical expansion coefficient.
(8) At melting point.
(9) 68° to 212° F.

WEIGHTS AND SPECIFIC GRAVITIES

Substance	Weight Lb. per Cu. Ft.	Specific Gravity
METALS, ALLOYS, ORES		
Aluminum, cast, hammered	165	2.55-2.75
Aluminum, bronze	481	7.7
Brass, cast, rolled	534	8.4-8.7
Bronze, 7.9 to 14% Sn	509	7.4-8.9
Copper, cast, rolled	556	8.8-9.0
Copper ore, pyrites	262	4.1-4.3
Gold, cast, hammered	1205	19.25-19.3
Iron, cast, pig	450	7.2
Iron, wrought	485	7.6-7.9
Iron, steel	490	7.8-7.9
Iron ore, hematite	325	5.2
Iron ore, hematite loose	130-160	.....
Lead	710	11.37
Mercury	849	13.6
Nickel	565	8.9-9.2
Nickel, monel metal	556	8.8-9.0
Platinum, cast, hammered	1330	21.1-21.5
Silver, cast, hammered	656	10.4-10.6
Tin, cast, hammered	459	7.2-7.5
Zinc, cast, rolled	440	6.9-7.2
VARIOUS SOLIDS		
Hay and straw.....bales	20	.....
Cotton, Flax, Hemp	93	1.47-1.50
Glass, common	156	2.40-2.60
Leather	59	0.86-1.02
Paper	58	0.70-1.15
Rubber goods	94	1.0-2.0
Salt, granulated, piled	48	.....
Saltpeter	67	.....
Sulphur	125	1.93-2.07
Wool	82	1.32
TIMBER, U. S. SEASONED		
Moisture Content by Weight:		
Seasoned timber 15 to 20%		
Green timber up to 50%		
Ash, white, red	40	0.62-0.65
Cedar, white, red	22	0.32-0.38
Cypress	30	0.48
Fir, Douglas spruce	32	0.51
Fir, eastern	25	0.40
Elm, white	45	0.72
Hemlock	29	0.42-0.52
Hickory	49	0.74-0.84
Maple, hard	43	0.68
Maple, white	33	0.53
Oak, chestnut	54	0.86
Oak, live	59	0.95
Oak, red, black	41	0.65
Oak, white	46	0.74
Pine, Oregon	32	0.51
Pine, red	30	0.48
Pine, white	26	0.41
Pine, yellow, long-leaf	44	0.70
Pine, yellow, short-leaf	38	0.61
Poplar	30	0.48
Redwood, California	26	0.42
Spruce, white, black	27	0.40-0.46
Walnut, black	38	0.61
Walnut, white	26	0.41
VARIOUS LIQUIDS		
Alcohol, 100%	49	0.79
Acids, muriatic 40%	75	1.20
Acids, nitric 91%	94	1.50
Acids, sulphuric 87%	112	1.80
Lye, soda 66%	106	1.70
Oils, vegetable	58	0.91-0.94
Oils, mineral, lubricants	57	0.90-0.93
Water, ice	56	0.88-0.92
Water, snow, fresh fallen	8	.125
Water, sea water	64	1.02-1.03
REFRACTORIES		
Brick, fire clay	125-140	2.0-2.2
Brick, silica	100-112	1.6-1.8
Brick, chrome	180-190	2.9-3.1
Brick, magnesite	162-175	2.6-2.8
Chrome cement	135-145	.....
Fire clay	80-85	.....
Magnesite cement	130-140	.....
Silica cement	75-80	.....

Substance	Weight Lb. per Cu. Ft.	Specific Gravity
BRICK MASONRY		
Granite, syenite, gneiss	140	2.2-2.3
Common brick	120	1.8-2.0
Soft brick	100	1.5-1.7
CONCRETE MASONRY		
Cement, stone, sand	144	2.2-2.4
Cement, slag, etc.	130	1.9-2.3
Cement, cinder, etc.	100	1.5-1.7
VARIOUS BUILDING MATERIALS		
Ashes, cinders	40-45	.....
Cement, portland, loose	94	.....
Cement, portland, set	183	2.7-3.2
Lime, gypsum, loose	53-64	.....
Mortar, set	103	1.4-1.9
Slags, bank slag	67-72	.....
Slags, bank screenings	98-117	.....
Slags, machine slag	96	.....
Slags, slag sand	49-55	.....
EARTH, ETC., EXCAVATED		
Clay, dry	63	.....
Clay, damp, plastic	110	.....
Clay and gravel, dry	100	.....
Earth, dry, loose	76	.....
Earth, dry, packed	95	.....
Earth, moist, loose	78	.....
Earth, moist, packed	96	.....
Earth, mud, flowing	108	.....
Earth, mud, packed	115	.....
Riprap, limestone	80-85	.....
Riprap, sandstone	90	.....
Riprap, shale	105	.....
Sand, gravel, dry, loose	90-105	.....
Sand, gravel, dry, packed	100-120	.....
Sand, gravel dry, wet	118-120	.....
EXCAVATIONS IN WATER		
Sand or gravel	60	.....
Sand or gravel and clay	65	.....
Clay	80	.....
River mud	90	.....
Soil	70	.....
Stone riprap	65	.....
MINERALS		
Asbestos	153	2.1-2.8
Chalk	137	1.8-2.6
Clay, marl	137	1.8-2.6
Granite, syenite	175	2.5-3.1
Greenstone, trap	187	2.8-3.2
Gypsum, alabaster	159	2.3-2.8
Limestone, marble	165	2.5-2.8
Phosphate rock, apatite	200	3.2
Pumice, natural	40	0.37-0.90
Quartz, flint	165	2.5-2.8
Sandstone, bluestone	147	2.2-2.5
Shale, slate	175	2.7-2.9
Soapstone, talc	169	2.6-2.8
COAL AND COKE, PILED		
Coal, anthracite	47-58	.....
Coal, bituminous, lignite	40-54	.....
Peat, turf	20-26	.....
Charcoal	10-14	.....
Coke	23-32	.....
BITUMINOUS SUBSTANCES		
Asphaltum	81	1.1-1.5
Coal, anthracite	97	1.4-1.7
Coal, bituminous	84	1.2-1.5
Lignite	78	1.1-1.4
Peat, turf, dry	47	0.65-0.85
Charcoal, pine	23	0.28-0.44
Charcoal, oak	33	0.47-0.57
Coke	75	1.0-1.4
Graphite	131	1.9-2.3
Paraffine	56	0.87-0.91

The specific gravities of solids and liquids refer to water at 4°C., those of gases to air at 0°C. and 760 mm. pressure. The weights per cubic foot are derived from average specific gravities, except where stated that weights are for bulk, heaped or loose material, etc.

GAS COMBUSTION CONSTANTS

No.	Gas	Formula	Molecular Wt.	Lbs. per Cu. Ft.	Cu. Ft. per Lb.	Sp. Gr. Air = 1.000	Heat of Combustion B.t.u. per Cu. Ft. Gross	Heat of Combustion B.t.u. per Cu. Ft. Net	Heat of Combustion B.t.u. per Lb. Gross	Heat of Combustion B.t.u. per Lb. Net	Cu. Ft. per Cu. Ft. of Combustible: Required for Combustion O_2	N_2	Air	Flue Products CO_2	H_2O	N_2	Lbs. per Lb. of Combustible: Required for Combustion O_2	N_2	Air	Flue Products CO_2	H_2O	N_2
1	Carbon	C	12.000						14,140†	14,140†							2.667	8.873	11.540	3.667		8.873
2	Hydrogen	H_2	2.015	0.005327	187.723	0.06959	323.5	275.1	61,100	51,643	0.5	1.882	2.382		1.0	1.882	7.939	26.414	34.353		8.939	26.414
3	Oxygen	O_2	32.000	0.08461	11.819	1.1053																
4	Nitrogen (atmos.)	N_2	28.016	0.07439*	13.443*	0.9718*																
5	Carbon monoxide	CO	28.000	0.07404	13.506	0.9672	323.5**	323.5	4,369	4,369	0.5	1.882	2.382	1.0		1.882	0.571	1.900	2.471	1.571		1.900
6	Carbon dioxide	CO_2	44.000	0.1170	8.548	1.5282																
Paraffin Series C_nH_{2n+2}																						
7	Methane	CH_4	16.031	0.04243	23.565	0.5543	1014.7‡	913.8	23,912	21,533	2.0	7.528	9.528	1.0	2.0	7.528	3.992	13.282	17.274	2.745	2.248	13.282
8	Ethane	C_2H_6	30.046	0.08029*	12.455*	1.04882*	1781	1631	22,215	20,312	3.5	13.175	16.675	2.0	3.0	13.175	3.728	12.404	16.132	2.929	1.799	12.404
9	Propane	C_3H_8	44.062	0.1196*	8.365*	1.5617*	2572	2371	21,564	19,834	5.0	18.821	23.821	3.0	4.0	18.821	3.631	12.081	15.712	2.996	1.635	12.081
10	Iso-Butane	C_4H_{10}	58.077	0.1582*	6.321*	2.00654*	3251	2999	21,247	19,606	6.5	24.467	30.967	4.0	5.0	24.467	3.581	11.914	15.495	3.030	1.551	11.914
11	n-Butane	C_4H_{10}	58.077	0.1582*	6.321*	2.00654*	3353	3102	21,247	19,606	6.5	24.467	30.967	4.0	5.0	24.467	3.581	11.914	15.495	3.030	1.551	11.914
12	n-Pentane	C_5H_{12}	72.092	0.1904*	5.252*	2.4872*	3981	3679	20,908	19,322	8.0	30.114	38.114	5.0	6.0	30.114	3.551	11.815	15.366	3.052	1.499	11.815
13	n-Hexane	C_6H_{14}	86.107	0.2274*	4.398*	2.9704*	4667	4315	20,526	18,976	9.5	35.760	45.260	6.0	7.0	35.760	3.530	11.745	15.275	3.067	1.465	11.745
Olefin Series C_nH_{2n}																						
14	Ethylene	C_2H_4	28.031	0.07456	13.412	0.9740	1631	1530	21,884	20,525	3.0	11.293	14.293	2.0	2.0	11.293	3.425	11.395	14.820	3.139	1.285	11.395
15	Propylene	C_3H_6	42.046	0.1110*	9.007*	1.4504*	2336	2185	21,042	19,683	4.5	16.939	21.439	3.0	3.0	16.939	3.425	11.395	14.820	3.139	1.285	11.395
16	Butylene	C_4H_8	56.062	0.1480*	6.756*	1.9336*	3135	2884	20,840	19,481	6.0	22.585	28.585	4.0	4.0	22.585	3.425	11.395	14.820	3.139	1.285	11.395
17	Acetylene	C_2H_2	26.015	0.06971	14.344	0.9107	1503	1453	21,572	20,840	2.5	9.411	11.911	2.0	1.0	9.411	3.075	10.231	13.306	3.383	0.692	10.231
Aromatic Series C_nH_{2n-6}																						
18	Benzene	C_6H_6	78.046	0.2060*	4.852*	2.6920*	3741	3590	18,150	17,418	7.5	28.232	35.732	6.0	3.0	28.232	3.075	10.231	13.306	3.383	0.692	10.231
19	Toluene	C_7H_8	92.062	0.2431*	4.113*	3.1760*	4408	4206	18,129	17,301	9.0	33.878	42.878	7.0	4.0	33.878	3.128	10.407	13.535	3.346	0.783	10.407
20	Xylene	C_8H_{10}	106.077				5155		18,410		10.5	39.524	50.024	8.0	5.0	39.524	3.168	10.540	13.708	3.318	0.849	10.540
21	Naphthalene	$C_{10}H_8$	128.062				5859		17,298		12.0	45.170	57.170	10.0	4.0	45.170	2.999	9.978	12.977	3.436	0.563	9.978
Miscellaneous Gases																						
22	Ammonia	NH_3	17.031	0.04563*	21.914*	0.5961	433		9,598													
23	Hydrogen sulfide	H_2S	34.080	0.09109*	10.979*	1.1898*	672		7,479		1.5	5.646	7.146	SO_2 = 1.0	1.0	5.646	1.408	4.685	6.093	SO_2 = 1.880	0.529	4.685
24	Sulfur dioxide	SO_2	64.06	0.1733	5.770	2.264																
25	Water vapor	H_2O	18.015	0.04758*	21.017*	0.6215*																
26	Air		28.9	0.07655	13.063	1.0000																

NOTES:

All gas volumes corrected to 60° F. and 30″ Hg dry.

Molecular weights calculated from atomic weights given in the International Critical Tables.

* Densities calculated from values given in grams per liter at 0° C. and 760 mm. in the International Critical Tables allowing for the known deviations from the gas laws. Where the coefficient of expansion was not available, the assumed value was taken as 0.0037 per ° C. Compare this with 0.003662 which is the coefficient for a perfect gas. Where no densities were available the volume of the mol was taken as 22.4115 liters. The asterisk (*) denotes that either the density or the coefficient of expansion has been assumed.

Some of the materials cannot exist as gases at 60° F. and 30″ Hg pressure, in which case the values are theoretical ones given for ease of calculation of gas problems. Under the actual concentrations in which these materials are present their partial pressure is low enough to keep them as gases.

The heats of combustion have been obtained by reviewing the experimental and critical data available. The 1929 A.G.A. Chemical Committee examined and approved the selection for the Gas Chemists Handbook. As far as possible the net heat of combustion per lb. is the base figure from which all others were calculated. The data, given in mean B.t.u. per lb. ($^1/_{180}$th of the heat per lb. of water from 32° F. to 212° F.) have been compiled largely from Bureau of Standards publications, Bulletins of the Univ. of Illinois Engineering Exp. Station, International Critical Tables, etc.

† Carbon—Roth and Naesser, Z. für Elektrochemie 31:461 (1925). White and black diamonds.

‡ Methane—Research Paper 260, Bureau of Standards (Jan. 1931) corrected. C_5H_{10}, $C_{10}H_8$, H_2S and NH_3 from 1929 A.G.A. Gas Chemists Handbook.

For precise calculations with gases saturated with water vapor, 1.73% of the B.t.u. value must be deducted to correct for the presence of water vapor.

Gross heating values are calculated from the net by allowing for the heat of vaporization of water at 60° F., amounting to 50.3 B.t.u. per cu. ft. of water vapor or 1057.8 B.t.u. per lb.

** Rossini in Bureau of Standards Research Paper 260 finds the heat of combustion of carbon monoxide to be 321.7 B.t.u. per cu. ft. Although not adopted for this edition, there is reason to believe that Rossini's value is the most accurate now available.

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COMBUSTION REACTIONS

Heats of Combustion at 60° F, and Flame Temperatures for Carbon, Hydrogen, and Some of Their Components

Carbon as Graphite

Reaction	Heat of combustion at 60°F			Max. flame temp., °F; corrected for dissociation (burned with theoret. air)
	Gross	Net	Btu per lb or cu ft	
$C + \frac{1}{2}O_2 \rightarrow CO$	3,964.	3,964.	lb	
$C + O_2 \rightarrow CO_2$	14,155.	14,155.	lb	3,820
$CO + \frac{1}{2}O_2 \rightarrow CO_2$	323.4	323.4	cu ft	3,960
$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$	325.1	274.8	cu ft	3,960
$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	1,010.7	909.8	cu ft	3,640
$C_2H_6 + 3\frac{1}{2}O_2 \rightarrow 2CO_2 + 3H_2O$	1,783.3	1,630.4	cu ft	3,710
$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$	2,572.	2,365.	cu ft	3,770
C_4H_{10}(iso) $+ 6\frac{1}{2}O_2 \rightarrow 4CO_2 + 5H_2O$	3,353.	3,093.	cu ft	3,780
C_5H_{12}(n) $+ 8O_2 \rightarrow 5CO_2 + 6H_2O$	3,987.	3,685.	cu ft	3,720
$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$	1,606.1	1,504.6	cu ft	3,910
$C_3H_6 + 4\frac{1}{2}O_2 \rightarrow 3CO_2 + 3H_2O$	2,332.	2,181.	cu ft	3,330
C_4H_8(iso) $+ 6O_2 \rightarrow 4CO_2 + 4H_2O$	3,077.	2,876.	cu ft	3,810
$C_2H_2 + 2\frac{1}{2}O_2 \rightarrow 2CO_2 + H_2O$	1,498.3	1,447.4	cu ft	4,250
$C_6H_6 + 7\frac{1}{2}O_2 \rightarrow 6CO_2 + 3H_2O$	3,744.	3,593.	cu ft	3,860
	*l*17,980.	17,250.	lb	3,840
$C_7H_8 + 9O_2 \rightarrow 7CO_2 + 4H_2O$	*l*18,300.	17,470.	lb	3,850
$C_{10}H_8 + 12O_2 \rightarrow 10CO_2 + 4H_2O$	*s*17,290.	16,690.	lb	

The cubic foot is measured at 60°F and 30 in. Hg.
Densities of C_3H_6, C_4H_8, C_5H_{12}, and C_6H_6 computed from the gas laws.
All gases are dry.
l = liquid, *s* = solid.

[1] Computed from I.C.T. values.

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PROPERTIES OF AIR AT ELEVATED TEMPERATURES

Temperature degrees F	Gas gravity	Density in lb per cu ft	Volume of 1 cu ft 60° air (or gas)	Volume of 1 lb dry air in cu ft	Heat content of dry air			% Volume of water vapor in saturated air	Viscosity lb/sec ft	Thermal Conductivity Btu ft / hr sq ft °F
					Btu/lb	Btu/cu ft of heated air	Btu/cu ft of 60° air			
60	1.000	0.0763	1.00	13.1	0	0	0	1.74	0.0000119	0.0136
80	0.962	0.0734	1.04	13.6	4.73	0.347	.361	3.45	0.0000125	0.0140
100	0.928	0.0708	1.08	14.1	9.46	0.670	.722	6.46	0.0000128	0.0145
120	0.897	0.0684	1.12	14.6	14.4	0.985	1.10	11.6	0.0000131	0.0149
140	0.867	0.0662	1.15	15.1	19.2	1.27	1.46	19.7	0.0000133	0.0153
160	0.839	0.0640	1.19	15.6	24.0	1.54	1.83	32.3	0.0000139	0.0158
180	0.812	0.0620	1.23	15.1	28.8	1.79	2.20	51.1	0.0000142	0.0162
200	0.787	0.0602	1.27	16.6	33.6	2.02	2.56	78.5	0.0000144	0.0166
250	0.733	0.0559	1.36	17.9	45.7	2.56	3.49	....	0.0000153	0.0174
300	0.684	0.0522	1.46	19.1	57.7	3.01	4.40	....	0.0000161	0.0182
400	0.604	0.0461	1.66	21.7	81.8	3.77	6.24	....	0.0000175	0.0200
500	0.541	0.0413	1.85	24.2	106	4.38	8.09	....	0.0000186	0.0214
600	0.493	0.0375	2.03	26.7	130	4.88	9.92	....	0.0000200	0.0229
700	0.450	0.0343	2.22	29.2	155	5.32	11.8	....	0.0000211	0.0243
800	0.415	0.0316	2.41	31.6	179	5.66	13.7	....	0.0000222	0.0257
900	0.383	0.0292	2.61	34.2	203	5.93	15.5	....	0.0000236	0.0270
1000	0.356	0.0272	2.81	36.8	235	6.39	17.9	....	0.0000247	0.0283
1200	0.313	0.0239	3.19	41.8	289	6.91	22.1	....	0.0000270	0.0308
1400	0.280	0.0214	3.57	46.8	343	7.32	26.2	....	0.0000292	0.0328
1600	0.253	0.0193	3.95	51.8	398	7.68	30.4	....	0.0000311	0.0346
1800	0.230	0.0176	4.34	56.9	455	8.00	34.7	....	0.0000333	0.0360
2000	0.211	0.0161	4.73	62.0	509	8.21	38.8	....	0.0000353	0.0370
2500	0.176	0.0134	5.68	74.5	....	....	....	....	.....	....
3000	0.151	0.0115	6.64	87.1	....	....	....	....	.....	....

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COMBUSTION CHARACTERISTICS OF TYPICAL GASES

(CALCULATED ON DRY BASIS)

Kind of Gas	Constituents of Gas—Per Cent by Volume										Specific Gravity	B.t.u. per Cu. Ft.		Cu. Ft. of Air per Cu. Ft. of Gas	Products of Combustion per Volume of Gas			Ultimate CO_2
	CO_2	O_2	N_2	CO	H_2	Ill.	CH_4	C_2H_6	C_3H_8	C_4H_{10}		Gross	Net		CO_2	H_2O Vapor	N_2	
Natural Gas, Kettleman Hills, California—Stripped Casinghead	...	...	...	...	...	...	85.4	8.6	5.1	0.9	.67	1183	1071	11.06	1.215	2.215	8.742	12.2
Natural Gas, Long Beach, Los Angeles Basin, California — Stripped Casinghead	0.5	.	...	..	...	...	86.8	7.2	4.3	1.2	.66	1161	1051	10.87	1.194	2.184	8.587	12.2
Natural Gas, San Joaquin Valley, California—Dry	0.1	...	1.2	...	...	...	98.7	..	..	...	.56	1000	902	9.40	.987	1.974	7.442	11.7
Natural Gas, Gulf Coast Area, Texas—Stripped	0.2	1.0	7.7	..	.	. .	88.8	2.3	...	...	.61	941	849	8.80	.934	1.845	7.027	11.7
Natural Gas—Texas Panhandle	0.1	0.1	7.7	..	...	...	82.2	6.1	2.4	1.4	.67	1052	952	9.85	1.076	1.997	7.882	12.0
Natural Gas, West Virginia	0.8	...	1.1	..	...	...	75.0	23.1	...	...	.69	1174	1064	11.00	1.212	2.193	8,700	12.2
Natural Gas—Casinghead, Unstripped	1.0	...	1.1	..	...	...	66.6	31.3	...	...	.74	1236	1122	11.56	1.292	2.271	9.148	12.4
Natural Gas—Sour	...	..	..	H_2S	6.4	.	58.7	16.5	9.9	8.5	.91	1478	1348	13.79	1.589 SO_2 .064	2.589	11.094	12.5
Coal Gas (Horizontal Retort)	2.1	0.4	3.5	8.7	50.5	3.8	28.2	2.8	..	...	.43	612	549	5.28	.568	1.240	4.241	11.8
Coal Gas (Horizontal Retort)	2.8	0.6	8.8	7.4	41.6	4.5	34.3	...	...	...	.49	606	545	5.27	.589	1.206	4.299	12.1
Coal Gas (Vertical Retort)	3.0	0.6	3.1	7.0	50.4	3.1	32.8	..	...	...	.41	587	525	5.06	.527	1.231	4.060	11.5
By-Product Coke Oven Gas	2.1	0.4	6.1	5.0	52.9	3.2	30.3	...	...	...	.40	565	505	4.86	.476	1.209	3.935	10.8
By-Product Coke Oven Gas	1.5	0.3	5.0	5.0	58.0	2.8	27.4	...	...	...	.36	544	484	4.64	.429	1.192	3.741	10.3
By-Product Coke Oven Gas	2.5	0.8	10.1	11.1	47.6	3.4	24.5	...	...	...	.47	513	461	4.35	.490	1.044	3.571	12.1
By-Product Coke Oven Gas	2.3	1.5	12.0	7.8	46.8	4.0	24.6	1.0	...	...	.48	532	478	4.51	.495	1.082	3.723	11.7
Carburetted Water Gas—Gas Oil Enrichment	3.3	0.7	3.8	33.4	38.1	10.7	10.0	...	...	...	.65	563	520	4.53	.799	.827	3.822	17.3
Carburetted Water Gas—Heavy Oil with Blow-Run	4.6	0.6	16.7	24.1	32.5	10.3	9.0	2.2	...	...	.71	535	494	4.38	.740	.808	3.825	16.2
Carburetted Water Gas—Heavy Oil with Blow-Run	5.8	0.6	11.5	25.0	34.4	9.2	13.5	...	...	...	.68	527	485	4.32	.737	.826	3.717	16.5
Carburetted Water Gas—Heavy Oil with Reforming and Blow Run	5.3	0.6	12.8	21.9	36.5	8.3	14.6	...	...	...	.65	515	472	4.24	.684	.848	3.648	15.8
Carburetted Water Gas—High Heating Value	1.1	0.6	3.8	13.7	30.5	15.8	33.1	1.4	...	...	.63	820	753	7.23	.986	1.404	5.754	14.6
Uncarburetted Water Gas	6.2	0.3	3.0	39.2	49.0	...	2.3		...	...	.55	309	281	2.31	.477	.536	1.852	20.5
Butane Air Gas	. .	17.6	66.4	...	...	...	...	...	...	16.0	1.17	544	503	4.11	.640	.800	3.915	14.1
Propane Air Gas	...	16.6	62.4		..	...	...	...	21.0	...	1.12	544	501	4.21	.630	.840	3.952	13.7
Propane Air Gas	...	14.5	54.6	..	. .	..	...	...	30.9	...	1.17	801	737	6.67	.927	.1236	5.815	13.7
Refinery Oil Gas—Liquid Phase Cracking (Cross Still)	...	0.2	0.6	1.2	6.1	15.0	4.4	72.5	...	...	1.00	1665	1530	15.35	1.926	2.654	12.208	13.6
Refinery Oil Gas—Vapor Phase Cracking (Gyro Still)	0.1	1.0	...	1.2	13.1	39.6	23.3	21.7	...	...	.88	1465	1350	13.20	1.789	2.119	10.626	14.4
Reformed Refinery Oil Gas	4.0	0.6	4.8	18.2	52.1	3.6	16.7	...	...	...	.47	476	429	3.93	.504	.938	3.189	13.6
Reformed Natural Gas—Water Gas Generator	1.9	0.2	6.5	17.1	39.1	2.3	32.9	...	...	...	.50	566	511	4.91	.593	1.102	3.964	13.0
Oil Gas	3.0	0.6	4.4	9.7	50.2	4.0	28.1	...	...	...	.44	567	509	4.85	.536	1.156	3.912	12.1
Producer Gas—Anthracite	6.6	...	49.0	25.1	18.7	0.3	0.3	...	...	...	.84	151	141	1.13	.330	.200	1.386	19.2
Producer Gas — Bituminous	2.5	0.3	55.3	27.0	12.0	0.4	2.5	...	...	...	.87	160	151	1.23	.333	.179	1.529	17.9
Blast Furnace Gas	9.4	...	61.8	27.8	1.0	...	...	...	...	...	1.01	93	92	.69	.372	.010	1.160	24.3

AVERAGE FLUE GAS DEW POINT FOR VARIOUS FUELS*

Fuel	*Average dew point (Temperature, °F)*
Anthracite	68
Semi-bituminous coal	84
Bituminous coal	93
Oil	111
Natural gas	127
Manufactured gas	137
Propane gas (2,500 Btu/cu ft)	119
Butane gas (3,200 Btu/cu ft)	124
Butane-air gas mixture (535 Btu/cu ft)	121

* American Society for Testing Materials

CHARACTERISTICS OF SIMPLE GASES

Simple Gases and Compounds	Critical Temperature ° F.	Critical Pressure, Lbs. per Sq. In. Absolute	Limits of Inflammability Lower % by Volume Gas in Air	Limits of Inflammability Upper % by Volume Gas in Air	Ignition Temperature	Combustion Velocity of Maximum Speed Mixture in Feet per Second	Toxicity: Maximum Amt. Inhaled for One Hour without Serious Disturbance, P.P.M.	Toxicity: Dangerous in 30 Minutes to One Hour, P.P.M.	Toxicity: Rapidly Fatal, P.P.M.	Solubility in Lbs. per Lb. Water 60° F. 30" Hg	Thermal Conductivity, B.t.u. per S.F. per °F. per In. per Sec.	Specific Gravity of the Liquid 60/60° F.	Heat of Vaporization at 60° F. B.t.u. per Lb.
H_2	−400	188	4.1	74	1076–1094	8.2*	Simple asphyxiant			0.0$_5$167	0.0$_3$05	..	...
O_2	−181	731	..	...	.....	..	.....	.....	....	0.0$_4$9	0.0$_4$47	..	...
N_2	−233	492	..	...	.....	..	Simple asphyxiant			0.0$_4$22	0.0$_4$38	..	...
CO	−218	515	12.5	74	1191–1216	1.6*	1000–1200	1500–2000	4,000	Very slight	0.0$_4$412	..	...
CO_2	88	1,073	..	...	.....	..	5 to 7% respiratory stimulant			0.0019	0.0$_4$263	..	...
CH_4	−116	673	5.3	14.0	1200–1382	1.2*	.... Simple asphyxiant			.....	0.0$_4$564	..	223
C_2H_6	90	717	3.2	12.5	968–1166	..	Simple asphyxiant			.....	0.0$_4$346	0.38	210
C_3H_8	204	632	2.4	9.5	965 approx.	..	Anesthetic			.....	.....	0.51	183
n-C_4H_{10}	308	529	1.9	8.5	930 approx.	1.03	Anesthetic			.....	.....	0.58	166
iso-C_4H_{10}	273	544	..	...	.....	..	.....	.....	....	.....	.....	0.56	159
n-C_5H_{12}	387	485	1.4	8.0	890 approx.	..	Anesthetic, convulsive, irritant			.....	0.0$_4$223	0.63	153
iso-C_5H_{12}	370	482	..	...	.....	..	Anesthetic, convulsive, irritant			.....	.....	..	...
C_6H_{14}	455	434	..	...	.....	..	Anesthetic, convulsive, irritant			.....	0.0$_4$198	0.66	143
C_2H_4	49	748	3.3	34**	1000–1020	2.1*	Simple asphyxiant and anesthetic			.....	0.0$_4$314	..	...
C_3H_6	198	662	2.2	10	.....	..	Anesthetic			.....	.....	..	...
C_4H_8	...	...	1.7	9	.....	..	Anesthetic			.....	.....	..	...
C_2H_2	97	911	2.5	80	763–824	4.1*	Simple asphyxiant and anesthetic			.....	0.0$_4$332	..	...
C_6H_6	551	701	1.4	8.0	1364	..	3100–4700	.....	19,000	.....	0.0$_4$160	0.88	...
C_7H_8	609	612	1.3	6.75	1490	..	3100–4700	.....	19,000	.....	.....	..	...
C_8H_{10}	...	...	..	...	.....	..	3100–4700	.....	19,000	.....	.....	..	...
$C_{10}H_8$	...	...	..	...	.....	..	.....	.....	.....	.....	.....	..	...
NH_3	270	1,639	16	27	.....	..	300–500	.....	5,000–10,000	0.612	0.0$_4$384	..	...
H_2S	212	1,307	..	...	.....	..	200–300	500–700	1,000–3,000	0.00466	0.0$_4$230	..	...
H_2O	706	3,226	..	...	.....	..	.....	.....	....	.....	0.0$_4$417	..	1058
Air	−285	547	..	...	.....	..	.....	.....	....	.....	0.0$_4$428	..	...

* Passauer. Das Gas und Wasserfach 73:313. Apr. 1930.
** Maximum reported in Bulletin 279, Bureau of Mines.

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PERIODIC ARRANGEMENT OF THE ELEMENTS

ZERO GROUP	GROUP I R_2O	GROUP II RO	GROUP III R_2O_3	GROUP IV RH_4 RO_2	GROUP V RH_3 R_2O_5	GROUP VI RH_2 RO_3	GROUP VII RH R_2O_7	GROUP VIII		
	Hydrogen H = 1.008 No. 1									
Helium He = 4.003 No. 2	Lithium Li = 6.940 No. 3	Beryllium Be = 9.02 No. 4	Boron B = 10.82 No. 5	Carbon C = 12.01 No. 6	Nitrogen N = 14.008 No. 7	Oxygen O = 16.000 No. 8	Fluorine F = 19.00 No. 9			
Neon Ne = 20.183 No. 10	Sodium Na = 22.997 No. 11	Magnesium Mg = 24.32 No. 12	Aluminum Al = 26.97 No. 13	Silicon Si = 28.06 No. 14	Phosphorus P = 30.98 No. 15	Sulphur S = 32.06 No. 16	Chlorine Cl = 35.457 No. 17			
Argon A = 39.944 No. 18	Potassium K = 39.096 No. 19	Calcium Ca = 40.08 No. 20	Scandium Sc = 45.10 No. 21	Titanium Ti = 47.90 No. 22	Vanadium V = 50.95 No. 23	Chromium Cr = 52.01 No. 24	Manganese Mn = 54.93 No. 25	Iron Fe = 55.85 No. 26	Cobalt Co = 58.94 No. 27	Nickel Ni = 58.69 No. 28
	Copper Cu = 63.57 No. 29	Zinc Zn = 65.38 No. 30	Gallium Ga = 69.72 No. 31	Germanium Ge = 72.60 No. 32	Arsenic As = 74.91 No. 33	Selenium Se = 78.96 No. 34	Bromine Br = 79.916 No. 35			
Krypton Kr = 83.7 No. 36	Rubidium Rb = 85.48 No. 37	Strontium Sr = 87.63 No. 38	Yttrium Y = 88.92 No. 39	Zirconium Zr = 91.22 No. 40	Columbium Cb = 92.91 No. 41	Molybdenum Mo = 95.95 No. 42	Technetium Tc = 99. No. 43	Ruthenium Ru = 101.7 No. 44	Rhodium Rh = 102.91 No. 45	Palladium Pd = 106.7 No. 46
	Silver Ag = 107.88 No. 47	Cadmium Cd = 112.41 No. 48	Indium In = 114.76 No. 49	Tin Sn = 118.70 No. 50	Antimony Sb = 121.76 No. 51	Tellurium Te = 127.61 No. 52	Iodine I = 126.92 No. 53			
Xenon Xe = 131.3 No. 54	Cesium Cs = 132.91 No. 55	Barium Ba = 137.36 No. 56	Lanthanum La = 138.92 No. 57	Hafnium Hf = 178.6 No. 72	Tantalum Ta = 180.88 No. 73	Tungsten W = 183.92 No. 74	Rhenium Re = 186.31 No. 75	Osmium Os = 190.2 No. 76	Iridium Ir = 193.1 No. 77	Platinum Pt = 195.23 No. 78
	Gold Au = 197.2 No. 79	Mercury Hg = 200.61 No. 80	Thallium Tl = 204.39 No. 81	Lead Pb = 207.21 No. 82	Bismuth Bi = 209.00 No. 83	Polonium Po = 210. No. 84	Astatine At = 211. No. 85			
Radon Rn = 222. No. 86	Francium Fa = 223. No. 87	Radium Ra = 226.05 No. 88	Actinium Ac = 227.05 No. 89							

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GAS IGNITION TEMPERATURES AND EXPLOSIVE LIMITS IN AIR

Gas or Vapor	Ignition Temperature °F	Explosive Limits Lower Limit % by Volume	Upper Limit % by Volume
Carbon Monoxide	1204	12.5	74.0
Hydrogen	1085	4.1	74.2
Methane	999	5.3	14.0
Ethane	950	3.2	12.5
Propane	871	2.37	9.5
n-Butane	806	1.6	8.5
iso-Butane	1010	1.9	8.5
Pentane	588	1.45	7.5
Hexane	500	1.2	6.9
Ethylene	842	2.75	28.6
Propylene	927	2.0	11.1
Benzene	1000	1.5	8.0
Toluene	1026	1.27	7.0
Xylene	900	1.0	5.3
Acetylene	581*	2.5	80.
Naphthalene	1038	0.9	
Ammonia	1204	16.	25.
Hydrogen Sulphide	500	4.3	46.0

National Fire Protection Association excerpt from Bureau of Mines Report of Investigations 3567.

SAFE END-POINTS IN PURGING OPERATIONS INVOLVING VARIOUS COMBUSTIBLE AND INERT GASES

Combustible Gas or Vapor	Inert Gas	Safe End Point—% by Volume: Purging from Air to Gas Maximum Permissible Oxygen Content of Atmosphere in Container	Purging from Gas to Air Maximum Permissible Combustible Gas Content of Atmosphere in Container
Mixed Gas	Nitrogen	8.6	11.0
Carburetted Blue Gas	Nitrogen	8.0	11.8
Coal Gas	Nitrogen	9.0	10.0
Benzol Vapor	Nitrogen	11.6	4.8
Hydrogen	Carbon Dioxide	8.1	8.9
	Nitrogen	5.1	5.7
Carbon Monoxide	Carbon Dioxide	9.8	31.5
	Nitrogen	6.6	19.5
Methane	Carbon Dioxide	15.7	22.6
	Nitrogen	12.8	14.0
Ethane	Carbon Dioxide	14.0	11.7
	Nitrogen	11.4	7.2
Propane	Carbon Dioxide	14.9	10.8
	Nitrogen	11.9	6.4
Butane	Carbon Dioxide	15.0	9.2
	Nitrogen	12.4	5.6
Ethylene	Carbon Dioxide	12.2	10.0
	Nitrogen	10.3	6.3

S. S. Tomkins.

CALCULATING EXPLOSIVE LIMITS OF GAS MIXTURES IN AIR

Coward and his co-workers have arranged the Le Chatelier formula in the following form for calculating the limits in air of any mixture of combustible gases to which it is applicable:

$$L = \frac{100}{\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} + \cdots}$$

Where P_1, P_2 and P_3 are the proportions of each combustible gas present in the original mixture, free from air and inert gases so that

$$P_1 + P_2 + P_3 + \cdots = 100$$

and N_1, N_2, N_3 are the limits in air for each gas separately, no inert gases being present.

EXPLOSIVE LIMITS OF SELECTED INDUSTRIAL GASES IN AIR

Kind of Gas	Heating Value, B.t.u./ Cu. Ft.	Composition—% by Volume: CO_2	Ill.	O_2	CO	H_2	CH_4	C_2H_6	N_2	Explosive Limits Lower	Upper
Blue	310	6.2	0.0	0.3	39.2	49.0	2.3		3.0	6.9	69.5
	308	1.9	0.0	0.3	45.0	47.5	1.2		4.1	6.1	67.4
Carburetted	509	4.6	7.3	0.3	36.0	37.0	9.6		5.2	6.4	37.7
Blue	538	3.9	8.2	0.7	32.4	33.7	13.1		8.0	6.8	37.3
	541	5.7	10.2	0.7	26.1	28.3	8.1	1.9	19.0	7.3	31.6
Coal	549	2.4	2.7	0.4	9.7	44.9	28.9		11.0	5.6	30.8
		1.6	3.1	1.2	8.5	50.3	26.0		9.3	5.8	29.0
Coke Oven	631	1.9	3.9	0.4	6.3	54.4	31.5		1.6	5.0	28.4
	540	2.5	3.4	0.8	11.1	47.9	24.2		10.1	5.3	30.0
	547	2.3	4.0	1.5	7.8	46.8	24.6	1.0	12.0	6.0	28.4
"Mixed"	540	2.5	3.2	0.5	10.5	47.0	25.8		10.5	5.6	31.7
	540	3.8	5.7	1.3	22.4	38.5	18.1		10.2	6.3	34.0
	540	3.1	8.1	0.8	21.5	33.7	15.0	1.0	16.8	6.8	30.8
Producer	136	6.2	0.0	0.0	27.3	12.4	0.7		53.4	20.7	73.7
	118	5.4	0.0	0.0	26.6	9.3	0.4		58.3	18.6	*
Natural										4.8	13.5

S. S. Tomkins.

LAWS OF PERFECT GASES

A perfect gas is defined as one which obeys exactly the laws of Boyle, Charles, Joule and Avogadro. Actually there are no perfect gases, but air, oxygen, nitrogen and hydrogen are among those which conform closely to the above laws, except at very low temperatures.

Boyle's Law

When the temperature of a given weight of a perfect gas is held constant the volume and absolute pressure vary inversely.

That is $PV = C$ (a constant).

where P = Absolute pressure of the gas.

V = Specific volume of the gas.

t = Absolute temperature of the gas.

Also $PV = P_1V_1 = P_2V_2$ if $t = t_1 = t_2$

Charles' Law

When a perfect gas receives heat at constant volume, the absolute pressure varies directly as the absolute temperature. That is

$$\frac{P}{T} = C_1 \text{ (a constant)}$$

$$\text{Also } \frac{P}{T} = \frac{P_1}{T_1} = \frac{P_2}{T_2} \text{ if } V = V_1 = V_2.$$

$$\text{Also } \frac{PV}{T} = \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}.$$

Joule's Law

The internal energy of a perfect gas is a function of the temperature only. Thus mathematically, if a gas obeys Boyle's and Charles' laws, it must also obey Joule's law.

Avogadro's Law

Equal volumes of all perfect gases measured under the same temperature and pressure conditions contain the same number of molecules.

Dalton's Law of Partial Pressures

In a mixture of gases, each gas taken alone exerts a partial pressure equal to the pressure that it would exert if the same weight that is actually present in the mixture were present alone in the volume in question.

Characteristic Equation for a Perfect Gas

In the case of a perfect gas, the laws of Boyle and Charles may be combined into a single equation as follows:

$$PV = MRT$$

where P = absolute pressure (lbs. per sq. ft.)

V = volume of M pounds of gas at pressure P and temperature T (cu. ft.)

M = weight of the gas (lbs.)

R = gas constant of the particular gas (ft. lbs. per lb. per degree F.)

T = absolute temperature of the gas (degrees F.)

Example R for oxygen $= \dfrac{14.735 \times 144 \times 11.817}{1 \times (60° + 459.7°)}$

$= 48.25$ ft. lbs. per lb. per degree F.

(For cubic feet of oxygen per pound at 60° F. and 30 inches of mercury pressure, see page 24.)

Then 10 pounds of oxygen under a pressure of 200 lbs. per sq. in. gauge and a temperature of 100° F. would occupy the following volume:

$$V = \frac{10 \times 48.25\ (100 + 459.7)}{(200 + 14.696) \times 144} = 8.74 \text{ cu. ft.}$$

If it were then expanded to a volume of 80 cubic feet and 5 lbs. per sq. in. gauge pressure, the temperature would be reduced to:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{214.696 \times 144 \times 8.74}{559.7} = \frac{19.696 \times 144 \times 80}{T_2}$$

$T_2 = 470.0°$ F. absolute

$= 10.3°$ F.

The Pound Mol

This unit may be defined as the number of pounds of a given substance equal to the molecular weight of the substance.

One pound mol of all perfect gases at any given temperature and pressure will occupy the same volume. At 60° F. and 30 inches of mercury pressure the figure is 378.4 cubic feet for dry gas and 385 cubic feet for saturated gas.

As indicated in the table (below) there is always some departure from this figure, since there are no gases which obey Boyle's Law exactly.

The Universal Gas Constant

In a similar way, if M in the equation $PV = MRT$ be taken as equal to one pound mol, then $M \times R$ will equal a constant for all perfect gases. For the different units employed these will be:

Basis	*Lb. mol*	*Lb. mol*	*Lb. mol*	*Gram mol*
P(abs.)	Lbs. per sq. ft.	Lbs. per sq. in.	Inches of Hg.	Mm. of Hg.
V	Cu. ft.	Cu. ft.	Cu. ft.	Liters
T(abs.)	°F.	°F.	°F.	°C.
MR	1545	10.73	21.85	62.37

VALUES OF R AND THE GAS CONSTANT MR AND VOLUMES OF THE POUND MOL FOR CERTAIN GASES.

	R Ft.-Lbs. per lb. per degree F.	M Pound Mol.	MR The Gas Constant	Cubic Feet per Mol.
Hydrogen	767.04	2.016	1,546	378.8
Oxygen	48.24	32.000	1,544	378.1
Nitrogen	55.13	28.016	1,545	378.3
Nitrogen "Atmospheric"	54.85	28.161	1,545	378.4
Air	53.33	28.97	1,545	378.4
Water Vapor	85.72	18.016	1,544	378.2
Carbon Dioxide	34.87	44.010	1,535	375.9
Carbon Monoxide	55.14	28.010	1,544	378.2
Hyrodgen Sulphide	44.79	34.076	1,526	373.9
Sulphur Dioxide	23.56	64.060	1,509	369.6
Ammonia	89.42	17.032	1,523	373.1
Methane	96.18	16.042	1,543	377.9
Ethane	50.82	30.068	1,528	374.3
Propane	34.13	44.094	1,505	368.6
n-Butane	25.57	58.120	1,486	364.0
Iso-Butane	25.79	58.120	1,499	367.1
Ethylene	54.70	28.052	1,534	375.8
Propylene	36.01	42.078	1,515	371.1

CORRECTING GAS VOLUME FOR PRESSURE AND TEMPERATURE

(Multiply observed volume of saturated gas by factor to reduce to volume of saturated gas at 60 F. and under a pressure of 30 inches of mercury at 32 F.) National Bureau of Standards Circular 464—1948.

Temperature, °F	Total gas pressure—Inches of mercury										Total gas pressure—Inches of mercury																°F
	28.0	28.1	28.2	28.3	28.4	28.5	28.6	28.7	28.8	28.9	29.0	29.1	29.2	29.3	29.4	29.5	29.6	29.7	29.8	29.9	30.0	30.1	30.2	30.3	30.4	30.5	
32	0.9975	1.0011	1.0047	1.0083	1.0118	1.0154	1.0190	1.0226	1.0262	1.0298	1.0334	1.0369	1.0405	1.0441	1.0477	1.0513	1.0549	1.0585	1.0620	1.0656	1.0692	1.0728	1.0764	1.0800	1.0836	1.0871	32
33	.9952	0.9988	1.0023	1.0059	1.0095	1.0131	1.0166	1.0202	1.0238	1.0274	1.0310	1.0345	1.0381	1.0417	1.0453	1.0488	1.0524	1.0560	1.0596	1.0632	1.0667	1.0703	1.0739	1.0775	1.0811	1.0846	33
34	.9929	.9965	1.0001	1.0036	1.0072	1.0108	1.0143	1.0179	1.0215	1.0251	1.0286	1.0322	1.0358	1.0393	1.0429	1.0465	1.0501	1.0536	1.0572	1.0608	1.0643	1.0679	1.0715	1.0751	1.0786	1.0822	34
35	.9906	.9941	0.9977	1.0013	1.0048	1.0084	1.0120	1.0155	1.0191	1.0227	1.0262	1.0298	1.0333	1.0369	1.0405	1.0440	1.0476	1.0512	1.0547	1.0583	1.0619	1.0654	1.0690	1.0725	1.0761	1.0797	35
36	.9883	.9919	.9955	0.9990	1.0026	1.0061	1.0097	1.0132	1.0168	1.0204	1.0239	1.0275	1.0310	1.0346	1.0381	1.0417	1.0453	1.0488	1.0524	1.0559	1.0595	1.0630	1.0666	1.0702	1.0737	1.0773	36
37	.9860	.9896	.9931	.9967	1.0002	1.0038	1.0073	1.0109	1.0144	1.0180	1.0215	1.0251	1.0286	1.0322	1.0357	1.0393	1.0428	1.0464	1.0499	1.0535	1.0570	1.0606	1.0641	1.0676	1.0712	1.0747	37
38	.9838	.9873	.9908	.9944	0.9979	1.0015	1.0050	1.0086	1.0121	1.0156	1.0192	1.0227	1.0263	1.0298	1.0333	1.0369	1.0404	1.0440	1.0475	1.0511	1.0546	1.0581	1.0617	1.0652	1.0688	1.0723	38
39	.9815	.9850	.9886	.9921	.9956	0.9992	1.0027	1.0062	1.0098	1.0133	1.0168	1.0204	1.0239	1.0274	1.0310	1.0345	1.0381	1.0416	1.0451	1.0487	1.0522	1.0557	1.0593	1.0628	1.0663	1.0699	39
40	.9791	.9827	.9862	.9897	.9932	.9968	1.0003	1.0038	1.0074	1.0109	1.0144	1.0179	1.0215	1.0250	1.0285	1.0320	1.0356	1.0391	1.0426	1.0462	1.0497	1.0532	1.0567	1.0603	1.0638	1.0673	40
41	.9768	.9803	.9839	.9874	.9909	.9944	0.9979	1.0015	1.0050	1.0085	1.0120	1.0155	1.0191	1.0226	1.0261	1.0296	1.0331	1.0367	1.0402	1.0437	1.0472	1.0508	1.0543	1.0578	1.0613	1.0648	41
42	.9745	.9781	.9816	.9851	.9886	.9921	.9956	0.9991	1.0027	1.0062	1.0097	1.0132	1.0167	1.0202	1.0237	1.0272	1.0308	1.0343	1.0378	1.0413	1.0448	1.0483	1.0518	1.0554	1.0589	1.0624	42
43	.9722	.9757	.9792	.9827	.9862	.9897	.9932	.9968	1.0003	1.0038	1.0073	1.0108	1.0143	1.0178	1.0213	1.0248	1.0283	1.0318	1.0353	1.0388	1.0423	1.0459	1.0494	1.0529	1.0564	1.0599	43
44	.9699	.9734	.9769	.9804	.9839	.9874	.9909	.9944	0.9979	1.0014	1.0049	1.0084	1.0119	1.0154	1.0189	1.0224	1.0259	1.0294	1.0329	1.0364	1.0399	1.0434	1.0469	1.0504	1.0539	1.0574	44
45	.9676	.9711	.9746	.9781	.9816	.9850	.9885	.9920	.9955	0.9990	1.0025	1.0060	1.0095	1.0130	1.0165	1.0200	1.0235	1.0270	1.0305	1.0339	1.0374	1.0409	1.0444	1.0479	1.0514	1.0549	45
46	.9653	.9688	.9723	.9757	.9792	.9827	.9862	.9897	.9932	.9967	1.0001	1.0036	1.0071	1.0106	1.0141	1.0176	1.0211	1.0246	1.0280	1.0315	1.0350	1.0385	1.0420	1.0455	1.0490	1.0524	46
47	.9629	.9664	.9699	.9734	.9768	.9803	.9838	.9873	.9908	.9942	0.9977	1.0012	1.0047	1.0082	1.0116	1.0151	1.0186	1.0221	1.0256	1.0290	1.0325	1.0360	1.0395	1.0430	1.0464	1.0499	47
48	.9606	.9641	.9676	.9710	.9745	.9780	.9815	.9849	.9884	.9919	.9953	0.9988	1.0023	1.0058	1.0092	1.0127	1.0162	1.0196	1.0231	1.0266	1.0301	1.0335	1.0370	1.0405	1.0440	1.0474	48
49	.9583	.9617	.9652	.9687	.9721	.9756	.9791	.9825	.9860	.9895	.9929	.9964	0.9998	1.0033	1.0068	1.0102	1.0137	1.0172	1.0206	1.0241	1.0276	1.0310	1.0345	1.0380	1.0414	1.0449	49
50	.9560	.9594	.9629	.9663	.9698	.9732	.9767	.9802	.9836	.9871	.9905	.9940	.9975	1.0009	1.0044	1.0078	1.0113	1.0148	1.0182	1.0217	1.0251	1.0286	1.0320	1.0355	1.0390	1.0424	50
51	.9536	.9570	.9605	.9639	.9674	.9708	.9743	.9777	.9812	.9846	.9881	.9915	.9950	0.9984	1.0019	1.0054	1.0088	1.0123	1.0157	1.0192	1.0226	1.0261	1.0295	1.0330	1.0364	1.0399	51
52	.9513	.9547	.9582	.9616	.9650	.9685	.9719	.9754	.9788	.9823	.9857	.9892	.9926	.9961	0.9995	1.0029	1.0064	1.0098	1.0133	1.0167	1.0202	1.0236	1.0271	1.0305	1.0340	1.0374	52
53	.9489	.9523	.9557	.9592	.9626	.9660	.9695	.9729	.9764	.9798	.9832	.9867	.9901	.9936	.9970	1.0004	1.0039	1.0073	1.0107	1.0142	1.0176	1.0211	1.0245	1.0279	1.0314	1.0348	53
54	.9465	.9499	.9534	.9568	.9602	.9637	.9671	.9705	.9740	.9774	.9808	.9843	.9877	.9911	.9946	0.9980	1.0014	1.0049	1.0083	1.0117	1.0151	1.0186	1.0220	1.0254	1.0289	1.0323	54
55	.9442	.9476	.9510	.9545	.9579	.9613	.9647	.9682	.9716	.9750	.9784	.9819	.9853	.9887	.9921	.9956	0.9990	1.0024	1.0058	1.0093	1.0127	1.0161	1.0195	1.0230	1.0264	1.0298	55
56	.9418	.9452	.9486	.9520	.9554	.9589	.9623	.9657	.9691	.9725	.9759	.9794	.9828	.9862	.9896	.9930	.9965	0.9999	1.0033	1.0067	1.0101	1.0135	1.0170	1.0204	1.0238	1.0272	56
57	.9394	.9428	.9462	.9496	.9531	.9565	.9599	.9633	.9667	.9701	.9735	.9769	.9803	.9838	.9872	.9906	.9940	.9974	1.0008	1.0042	1.0076	1.0111	1.0145	1.0179	1.0213	1.0247	57
58	.9370	.9404	.9438	.9472	.9506	.9540	.9574	.9608	.9642	.9676	.9710	.9744	.9778	.9812	.9846	.9881	.9915	.9949	0.9983	1.0017	1.0051	1.0085	1.0119	1.0152	1.0187	1.0221	58
59	.9346	.9380	.9414	.9448	.9482	.9516	.9550	.9584	.9618	.9652	.9686	.9720	.9754	.9788	.9822	.9856	.9890	.9924	.9958	0.9992	1.0026	1.0060	1.0094	1.0128	1.0162	1.0196	59
60	.9321	.9355	.9389	.9423	.9457	.9491	.9525	.9559	.9593	.9627	.9661	.9695	.9729	.9762	.9796	.9830	.9864	.9898	.9932	.9966	1.0000	1.0034	1.0068	1.0102	1.0136	1.0170	60
61	.9297	.9331	.9365	.9399	.9433	.9467	.9501	.9534	.9568	.9602	.9636	.9670	.9704	.9738	.9772	.9805	.9839	.9873	.9907	.9941	0.9975	1.0009	1.0042	1.0076	1.0110	1.0144	61
62	.9273	.9307	.9340	.9374	.9408	.9442	.9476	.9509	.9543	.9577	.9611	.9644	.9678	.9712	.9746	.9780	.9813	.9847	.9881	.9915	.9949	0.9982	1.0016	1.0050	1.0084	1.0118	62
63	.9248	.9282	.9316	.9350	.9383	.9417	.9451	.9485	.9518	.9552	.9586	.9619	.9653	.9687	.9721	.9754	.9788	.9822	.9856	.9889	.9923	.9957	0.9990	1.0024	1.0058	1.0092	63
64	.9224	.9257	.9291	.9325	.9358	.9392	.9426	.9459	.9493	.9527	.9560	.9594	.9628	.9661	.9695	.9729	.9762	.9796	.9830	.9863	.9897	.9931	.9964	0.9998	1.0032	1.0065	64
65	.9199	.9233	.9266	.9300	.9334	.9367	.9401	.9434	.9468	.9502	.9535	.9569	.9602	.9636	.9670	.9703	.9737	.9770	.9804	.9838	.9871	.9905	.9938	.9972	1.0006	1.0039	65
66	.9174	.9208	.9241	.9275	.9308	.9342	.9375	.9409	.9442	.9476	.9509	.9543	.9576	.9610	.9644	.9677	.9711	.9744	.9778	.9811	.9845	.9878	.9912	.9945	0.9979	1.0012	66
67	.9149	.9183	.9216	.9250	.9283	.9317	.9350	.9383	.9417	.9450	.9484	.9517	.9551	.9584	.9618	.9651	.9685	.9718	.9752	.9785	.9819	.9852	.9886	.9919	.9953	0.9986	67
68	.9124	.9157	.9190	.9224	.9257	.9291	.9324	.9357	.9391	.9424	.9458	.9491	.9524	.9558	.9591	.9625	.9658	.9692	.9725	.9758	.9792	.9825	.9859	.9892	.9925	.9959	68
69	.9099	.9132	.9165	.9199	.9232	.9265	.9299	.9332	.9365	.9399	.9432	.9465	.9499	.9532	.9566	.9599	.9632	.9666	.9699	.9732	.9766	.9799	.9832	.9866	.9899	.9932	69
70	.9073	.9106	.9139	.9173	.9206	.9239	.9273	.9306	.9339	.9372	.9406	.9439	.9472	.9506	.9539	.9572	.9605	.9639	.9672	.9705	.9739	.9772	.9805	.9838	.9872	.9905	70

Temperature, °F	Total gas pressure—Inches of mercury										Total gas pressure—Inches of mercury																°F
	28.0	28.1	28.2	28.3	28.4	28.5	28.6	28.7	28.8	28.9	29.0	29.1	29.2	29.3	29.4	29.5	29.6	29.7	29.8	29.9	30.0	30.1	30.2	30.3	30.4	30.5	
71	0.9048	0.9081	0.9114	0.9147	0.9180	0.9214	0.9247	0.9280	0.9313	0.9346	0.9380	0.9413	0.9446	0.9479	0.9513	0.9546	0.9579	0.9612	0.9645	0.9679	0.9712	0.9745	0.9778	0.9812	0.9845	0.9878	71
72	.9022	.9055	.9088	.9121	.9154	.9188	.9221	.9254	.9287	.9320	.9353	.9387	.9420	.9453	.9486	.9519	.9552	.9586	.9619	.9652	.9685	.9718	.9751	.9784	.9818	.9851	72
73	.8996	.9029	.9062	.9095	.9128	.9161	.9194	.9228	.9261	.9294	.9327	.9360	.9393	.9426	.9459	.9492	.9525	.9559	.9592	.9625	.9658	.9691	.9724	.9757	.9790	.9823	73
74	.8970	.9003	.9036	.9069	.9102	.9135	.9168	.9201	.9234	.9267	.9300	.9333	.9366	.9399	.9432	.9465	.9498	.9531	.9564	.9597	.9630	.9664	.9697	.9730	.9763	.9796	74
75	.8944	.8977	.9010	.9043	.9076	.9108	.9141	.9174	.9207	.9240	.9273	.9306	.9339	.9372	.9405	.9438	.9471	.9504	.9537	.9570	.9603	.9636	.9669	.9702	.9735	.9768	75
76	.8917	.8950	.8983	.9015	.9048	.9081	.9114	.9147	.9180	.9213	.9246	.9279	.9312	.9345	.9377	.9410	.9443	.9476	.9509	.9542	.9575	.9608	.9641	.9674	.9707	.9739	76
77	.8890	.8923	.8956	.8989	.9022	.9055	.9088	.9120	.9153	.9186	.9219	.9252	.9285	.9318	.9350	.9383	.9416	.9449	.9482	.9515	.9547	.9580	.9613	.9646	.9679	.9712	77
78	.8864	.8897	.8930	.8962	.8995	.9028	.9061	.9094	.9126	.9159	.9192	.9225	.9257	.9290	.9323	.9356	.9389	.9421	.9454	.9487	.9520	.9553	.9585	.9618	.9651	.9684	78
79	.8837	.8870	.8902	.8935	.8968	.9000	.9033	.9066	.9099	.9131	.9164	.9197	.9230	.9262	.9295	.9328	.9361	.9393	.9426	.9459	.9491	.9524	.9557	.9590	.9622	.9655	79
80	.8810	.8842	.8875	.8908	.8940	.8973	.9006	.9038	.9071	.9104	.9136	.9169	.9202	.9234	.9267	.9300	.9332	.9365	.9398	.9430	.9463	.9496	.9528	.9561	.9594	.9626	80
81	.8782	.8815	.8847	.8880	.8912	.8945	.8978	.9010	.9043	.9075	.9108	.9141	.9173	.9206	.9238	.9271	.9304	.9336	.9369	.9401	.9434	.9467	.9499	.9532	.9564	.9597	81
82	.8754	.8787	.8819	.8852	.8884	.8917	.8950	.8982	.9015	.9047	.9080	.9112	.9145	.9177	.9210	.9242	.9275	.9308	.9340	.9373	.9405	.9438	.9470	.9503	.9535	.9568	82
83	.8726	.8759	.8791	.8824	.8856	.8889	.8921	.8954	.8986	.9019	.9051	.9083	.9116	.9148	.9181	.9213	.9246	.9278	.9311	.9343	.9376	.9408	.9441	.9473	.9506	.9538	83
84	.8698	.8731	.8763	.8796	.8828	.8861	.8893	.8925	.8958	.8990	.9023	.9055	.9088	.9120	.9152	.9185	.9217	.9250	.9282	.9315	.9347	.9379	.9412	.9444	.9477	.9509	84
85	.8670	.8702	.8734	.8767	.8799	.8832	.8864	.8896	.8929	.8961	.8993	.9026	.9058	.9090	.9123	.9155	.9188	.9220	.9252	.9285	.9317	.9349	.9382	.9414	.9447	.9479	85
86	.8641	.8674	.8706	.8738	.8771	.8803	.8835	.8868	.8900	.8932	.8965	.8997	.9029	.9061	.9094	.9126	.9158	.9191	.9223	.9255	.9288	.9320	.9352	.9385	.9417	.9449	86
87	.8612	.8644	.8677	.8709	.8741	.8773	.8806	.8838	.8870	.8902	.8935	.8967	.8999	.9031	.9064	.9096	.9128	.9160	.9193	.9225	.9257	.9289	.9322	.9354	.9386	.9418	87
88	.8583	.8615	.8648	.8680	.8712	.8744	.8776	.8808	.8841	.8873	.8905	.8937	.8969	.9002	.9034	.9066	.9098	.9130	.9163	.9195	.9227	.9259	.9291	.9324	.9356	.9388	88
89	.8554	.8586	.8618	.8650	.8682	.8714	.8746	.8779	.8811	.8843	.8875	.8907	.8939	.8971	.9004	.9036	.9068	.9100	.9132	.9164	.9196	.9228	.9261	.9293	.9325	.9357	89
90	.8524	.8556	.8588	.8620	.8652	.8685	.8717	.8749	.8781	.8813	.8845	.8877	.8909	.8941	.8973	.9005	.9037	.9069	.9101	.9134	.9166	.9198	.9230	.9262	.9294	.9326	90
91	.8494	.8526	.8558	.8590	.8622	.8654	.8686	.8718	.8750	.8782	.8814	.8846	.8878	.8910	.8942	.8974	.9006	.9038	.9070	.9102	.9134	.9166	.9198	.9230	.9262	.9294	91
92	.8464	.8496	.8528	.8560	.8592	.8624	.8656	.8688	.8720	.8752	.8784	.8816	.8848	.8879	.8911	.8943	.8975	.9007	.9039	.9071	.9103	.9135	.9167	.9199	.9231	.9263	92
93	.8433	.8465	.8497	.8529	.8561	.8593	.8625	.8656	.8688	.8720	.8752	.8784	.8816	.8848	.8880	.8912	.8944	.8975	.9007	.9039	.9071	.9103	.9135	.9167	.9199	.9231	93
94	.8403	.8434	.8466	.8498	.8530	.8562	.8594	.8625	.8657	.8689	.8721	.8753	.8785	.8816	.8848	.8880	.8912	.8944	.8976	.9008	.9039	.9071	.9103	.9135	.9167	.9199	94
95	.8371	.8403	.8435	.8467	.8498	.8530	.8562	.8594	.8626	.8657	.8689	.8721	.8753	.8784	.8816	.8848	.8880	.8912	.8943	.8975	.9007	.9039	.9070	.9102	.9134	.9166	95
96	.8340	.8372	.8404	.8435	.8467	.8499	.8530	.8562	.8594	.8626	.8657	.8689	.8721	.8753	.8784	.8816	.8848	.8879	.8911	.8943	.8975	.9006	.9038	.9070	.9102	.9133	96
97	.8308	.8340	.8371	.8403	.8435	.8466	.8498	.8530	.8561	.8593	.8625	.8656	.8688	.8720	.8751	.8783	.8815	.8846	.8878	.8910	.8941	.8973	.9005	.9036	.9068	.9100	97
98	.8276	.8308	.8339	.8371	.8403	.8434	.8466	.8497	.8529	.8561	.8592	.8624	.8655	.8687	.8719	.8750	.8782	.8814	.8845	.8877	.8908	.8940	.8972	.9003	.9035	.9066	98
99	.8243	.8275	.8306	.8338	.8370	.8401	.8433	.8464	.8496	.8527	.8559	.8590	.8622	.8653	.8685	.8717	.8748	.8780	.8811	.8843	.8874	.8906	.8937	.8969	.9001	.9032	99
100	.8211	.8243	.8274	.8306	.8337	.8369	.8400	.8432	.8463	.8495	.8526	.8558	.8589	.8621	.8652	.8684	.8715	.8747	.8778	.8810	.8841	.8873	.8904	.8936	.8967	.8999	100
101	.8178	.8209	.8241	.8272	.8304	.8335	.8367	.8398	.8430	.8461	.8492	.8524	.8555	.8587	.8618	.8650	.8681	.8713	.8744	.8775	.8807	.8838	.8870	.8901	.8933	.8964	101
102	.8144	.8176	.8207	.8238	.8270	.8301	.8333	.8364	.8395	.8427	.8458	.8489	.8521	.8552	.8584	.8615	.8646	.8678	.8709	.8741	.8772	.8803	.8835	.8866	.8897	.8929	102
103	.8110	.8142	.8173	.8204	.8236	.8267	.8298	.8330	.8361	.8392	.8424	.8455	.8486	.8518	.8549	.8580	.8612	.8643	.8674	.8706	.8737	.8768	.8800	.8831	.8862	.8894	103
104	.8076	.8107	.8138	.8170	.8201	.8232	.8263	.8295	.8326	.8357	.8389	.8420	.8451	.8482	.8514	.8545	.8576	.8607	.8639	.8670	.8701	.8733	.8764	.8795	.8826	.8858	104
105	.8041	.8072	.8104	.8135	.8166	.8197	.8229	.8260	.8291	.8322	.8353	.8385	.8416	.8447	.8478	.8510	.8541	.8572	.8603	.8634	.8666	.8697	.8728	.8759	.8791	.8822	105
106	.8006	.8037	.8069	.8100	.8131	.8162	.8193	.8224	.8256	.8287	.8318	.8349	.8380	.8411	.8443	.8474	.8505	.8536	.8567	.8598	.8630	.8661	.8692	.8723	.8754	.8785	106
107	.7971	.8002	.8033	.8064	.8095	.8126	.8157	.8188	.8220	.8251	.8282	.8313	.8344	.8375	.8406	.8437	.8468	.8500	.8531	.8562	.8593	.8624	.8655	.8686	.8717	.8748	107
108	.7935	.7966	.7997	.8028	.8059	.8090	.8121	.8152	.8183	.8214	.8245	.8276	.8307	.8339	.8370	.8401	.8432	.8463	.8494	.8525	.8556	.8587	.8618	.8649	.8680	.8711	108
109	.7899	.7930	.7961	.7992	.8023	.8054	.8085	.8116	.8147	.8178	.8209	.8240	.8271	.8302	.8333	.8364	.8395	.8426	.8457	.8488	.8519	.8550	.8581	.8612	.8643	.8674	109
110	.7862	.7893	.7924	.7954	.7985	.8016	.8047	.8078	.8109	.8140	.8171	.8202	.8233	.8264	.8295	.8326	.8357	.8388	.8419	.8450	.8481	.8511	.8542	.8573	.8604	.8635	110

[1] Formula used: Correction factor $= \frac{(p - w_t)(60 + 459.7)}{(t + 459.8)(30 - 0.5217)}$

p = total gas pressure; w_t = vapor pressure of water at $t°$; t = temperature of gas (°F).

VAPOR PRESSURES, POUNDS PER SQUARE INCH ABSOLUTE

Temperature, °F	Acetylene, C_2H_2	Ammonia, NH_3	Benzene, C_6H_6	n-Butane, C_4H_{10}	Isobutane, C_4H_{10}	Carbon Dioxide, CO_2	Carbon Disulfide, CS_2	Ethane, C_2H_6	Ethyl Alcohol, C_2H_5OH	Ethyl Chloride C_2H_5Cl	Hydrogen Sulfide, H_2S	Methyl Chloride, CH_3Cl	Naphthalene, $C_{10}H_8$ Dry	Naphthalene, $C_{10}H_8$ Moist	Propane, C_3H_8	Sulfur dioxide, SO_2	Toluene, C_7H_8	Water, H_2O	m-Xylene, C_8H_{10}
−20	162	18.30	...	...	7.50	215.02	0.53	158	0.022	2.16	57.5	11.75	....	....	25.4	5.883	...	....	...
−10	196	23.74	...	...	9.28	257.46	0.74	185	0.036	2.94	70.0	15.0	....	....	31.4	7.863	...	....	...
0	232	30.42	...	7.3	12.1	305.5	1.00	218	0.058	3.93	84.0	18.8	....	....	38.2	10.35	...	....	...
10	271	38.51	...	9.3	14.8	360.2	1.36	250	0.090	5.13	100	23.3	....	....	46.5	13.42	...	....	...
20	319	48.21	...	11.8	18.2	421.8	1.80	290	0.140	6.65	120	28.8	....	....	55.5	17.18	...	....	...
30	372	59.74	[a] 0.48	14.4	23.3	490.8	2.30	334	0.220	8.40	143	35.2	0.000096	0.000029	66.3	21.70	0.125	....	0.031
32	387	62.29	0.52	15.8	23.2	505.5	2.46	346	0.236	8.85	150	36.6	0.00011	0.000033	68.0	22.47	0.137	0.0887	0.034
40	430	73.32	0.66	18.4	26.9	567.8	2.96	381	0.330	10.53	169	42.6	0.00018	0.000057	78.0	27.10	0.176	0.1217	0.042
50	495	89.19	0.88	22.7	32.2	653.6	3.83	418	0.456	13.20	197	51.5	0.00034	0.00012	91.8	33.45	0.247	0.1780	0.061
60	565	107.6	1.14	27.1	38.7	748.6	4.75	496	0.640	16.5	230	61.6	0.00060	0.00026	107.1	40.93	0.335	0.2561	0.093
70	645	128.8	1.51	32.7	45.8	853.4	5.93	560	0.910	20.0	267	73.3	0.0011	0.00057	124.0	49.62	0.455	0.3628	0.131
80	735	153.0	1.95	39.0	53.9	968.7	7.30	632	1.25	24.3	302	85.3	0.0019	0.0013	142.8	59.68	0.607	0.5067	0.178
90	830	180.6	2.51	46.2	63.3	....	9.00	708	1.71	29.0	344	102.1	0.0032	0.0029	164.0	71.25	0.790	0.6980	0.241
100	..	211.9	3.20	55.0	74.7	....	10.8	..	2.32	34.9	392	118.8	0.0054	0.0054	187.0	84.52	1.03	0.9487	0.330
110	..	247.0	[a] 4.05	64.2	85.1	....	13.3	..	3.09	41.1	442	137.6	0.0088	0.0094	212.0	99.76	1.32	1.274	0.435
120	..	286.4	4.22	75	98.0	....	16.0	..	4.02	48.1	500	158.8	0.0142	0.016	240.0	120.9	1.70	1.692	0.570
130	..	329	6.41	87	112.0	....	19.0	..	5.27	56.3	560	173	0.0218	....	272	135.0	2.13	2.221	0.745
140	..	379	7.53	101	126.8	....	22.6	..	6.82	66.1	632	200	0.0322	....	...	157.8	2.70	2.887	0.978
150	..	435	9.2	115	....	....	26.5	..	8.65	76.0	700	223	0.0439	....	...	181	3.30	3.716	1.22
160	..	495	11.0	132	....	....	30.9	..	10.9	86.3	778	253	0.071	....	...	209	4.03	4.739	1.53
170	..	560	13.0	151	....	....	35.9	..	13.5	99.0	862	287	0.105	....	...	239	5.00	5.990	1.94
180	..	640	15.4	172	....	....	41.9	..	17.0	113	962	322	0.155	....	...	272	6.02	7.510	2.42
190	..	715	18.2	194	....	....	48.0	..	21.0	127	1050	360	0.217	....	...	309	7.3	9.336	2.98
200	..	800	21.7	219	....	....	55.2	..	25.5	142	1160	400	0.277	....	...	350	8.7	11.525	3.62
210	..	890	25.4	248	....	....	63.0	..	31.1	161	1280	445	0.347	....	...	399	10.3	14.123	4.42
220	..	990	...	...	....	....	71.5	..	37.8	180	....	495	0.419	....	...	449	...	17.188	5.30
230	..	1100	...	...	....	....	81.6	..	45.7	203	....	550	0.547	....	...	501	...	20.78	6.35
240	..	1210	...	...	....	....	91.8	..	54.5	230	....	605	0.68	....	...	561	...	24.97	7.55
250	..	1340	...	...	....	....	103	..	64.5	260	....	670	0.85	....	...	624	...	29.82	9.0
	[d]	[d, h]	[b, d]	[b, c, f]	[c, f]	[d, e, f]	[d]	[d]	[d]	[d, f]	[d]	[d, e]	[b, d]	[b]	[c, f]	[d, f]	[a, d]	[g]	[d]

[a] Gas Chemists Handbook, Third Edition, 1929.
[b] Gas Engineers' Handook, First Edition, 1934.
[c] Handbook of Butane-Propane Gases, Second Edition, 1935.
[d] Handbook of Chemistry and Physics, Nineteenth Edition, 1934.
[e] *Heating and Ventilating*, September and October 1938.
[f] L. S. Marks, Mechanical Engineers' Handbook, Third Edition, 1930.
[g] J. H. Keenan, "Steam Tables and Mollier Diagram," 1930.
[h] U. S. Bur. of Standards, Circular No. 142, 1923.

Note: Over small temperature intervals the logarithm of the vapor pressure plotted against temperature is practically a straight line. For longer temperature intervals the plot against reciprocal of the absolute temperature should be used.

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REDUCTION OF BAROMETRIC READINGS

This table gives the corrections in inches of mercury to convert readings at various temperatures to readings at standard temperature.

°F.	Observed reading of barometer in inches						
	24	25	26	27	28	29	30
0	+0.063	+0.065	+0.068	+0.070	+0.073	+0.076	+0.078
2	+0.058	+0.061	+0.063	+0.065	+0.068	+0.070	+0.073
4	+0.054	+0.056	+0.058	+0.061	+0.063	+0.065	+0.067
6	+0.049	+0.052	+0.054	+0.056	+0.058	+0.060	+0.062
8	+0.045	+0.047	+0.049	+0.051	+0.053	+0.054	+0.056
10	+0.041	+0.042	+0.044	+0.046	+0.047	+0.049	+0.051
12	+0.036	+0.038	+0.039	+0.041	+0.042	+0.044	+0.045
14	+0.032	+0.033	+0.035	+0.036	+0.037	+0.039	+0.040
16	+0.028	+0.029	+0.030	+0.031	+0.032	+0.033	+0.034
18	+0.023	+0.024	+0.025	+0.026	+0.027	+0.028	+0.029
20	+0.019	+0.020	+0.020	+0.021	+0.022	+0.023	+0.024
22	+0.014	+0.015	+0.016	+0.016	+0.017	+0.017	+0.018
24	+0.010	+0.011	+0.011	+0.011	+0.012	+0.012	+0.013
26	+0.006	+0.006	+0.006	+0.006	+0.007	+0.007	+0.007
28	+0.001	+0.001	+0.001	+0.002	+0.002	+0.002	+0.002
30	−0.003	−0.003	−0.003	−0.003	−0.003	−0.004	−0.004
32	−0.007	−0.008	−0.008	−0.008	−0.009	−0.009	−0.009
34	−0.012	−0.012	−0.013	−0.013	−0.014	−0.014	−0.015
36	−0.016	−0.017	−0.017	−0.018	−0.019	−0.019	−0.020
38	−0.020	−0.021	−0.022	−0.023	−0.024	−0.025	−0.026
40	−0.025	−0.026	−0.027	−0.028	−0.029	−0.030	−0.031
42	−0.029	−0.030	−0.032	−0.033	−0.034	−0.035	−0.036
44	−0.033	−0.035	−0.036	−0.038	−0.039	−0.040	−0.042
46	−0.038	−0.039	−0.041	−0.043	−0.044	−0.046	−0.047
48	−0.042	−0.044	−0.046	−0.047	−0.049	−0.051	−0.053
50	−0.046	−0.048	−0.050	−0.052	−0.054	−0.056	−0.058
52	−0.051	−0.053	−0.055	−0.057	−0.059	−0.061	−0.064
54	−0.055	−0.057	−0.060	−0.062	−0.064	−0.067	−0.069
56	−0.060	−0.062	−0.064	−0.067	−0.069	−0.072	−0.074
58	−0.064	−0.066	−0.069	−0.072	−0.074	−0.077	−0.080
60	−0.068	−0.071	−0.074	−0.077	−0.080	−0.082	−0.085
62	−0.073	−0.076	−0.079	−0.082	−0.085	−0.088	−0.091
64	−0.077	−0.080	−0.083	−0.086	−0.090	−0.093	−0.096
66	−0.081	−0.085	−0.088	−0.091	−0.095	−0.098	−0.101
68	−0.085	−0.089	−0.093	−0.096	−0.100	−0.103	−0.107
70	−0.090	−0.094	−0.097	−0.101	−0.105	−0.109	−0.112
72	−0.094	−0.098	−0.102	−0.106	−0.110	−0.114	−0.118
74	−0.098	−0.103	−0.107	−0.111	−0.115	−0.119	−0.123
76	−0.103	−0.107	−0.111	−0.116	−0.120	−0.124	−0.128
78	−0.107	−0.112	−0.116	−0.120	−0.125	−0.129	−0.134
80	−0.111	−0.116	−0.121	−0.125	−0.130	−0.135	−0.139
82	−0.116	−0.121	−0.125	−0.130	−0.135	−0.140	−0.145
84	−0.120	−0.125	−0.130	−0.135	−0.140	−0.145	−0.150
86	−0.124	−0.130	−0.135	−0.140	−0.145	−0.150	−0.155
88	−0.129	−0.134	−0.139	−0.145	−0.150	−0.155	−0.161
90	−0.133	−0.138	−0.144	−0.150	−0.155	−0.161	−0.166
92	−0.137	−0.143	−0.149	−0.154	−0.160	−0.166	−0.172
94	−0.142	−0.147	−0.153	−0.159	−0.165	−0.171	−0.177
96	−0.146	−0.152	−0.158	−0.164	−0.170	−0.176	−0.182
98	−0.150	−0.156	−0.163	−0.169	−0.175	−0.181	−0.188
100	−0.154	−0.161	−0.167	−0.174	−0.180	−0.187	−0.193

From table 44 of Smithsonian Meteorological Tables, 1939.

Example:

Observed height of barometer	=29.502
Attached thermometer, 68 degrees F.	
Reduction for temperature	= 0.105
Barometer reading corrected for temperature	=29.397

ATMOSPHERIC PRESSURE

This table is compiled from elevations and normal atmospheric pressures at United States Weather Bureau stations.

Elevation in feet	Inches mercury	Pounds absolute	Elevation in feet	Inches mercury	Pounds absolute
0	30.00	14.73	2000	27.90	13.70
100	29.89	14.68	2500	27.39	13.45
200	29.78	14.63	3000	26.90	13.21
300	29.67	14.57	3500	26.41	12.97
400	29.56	14.52	4000	25.93	12.74
500	29.45	14.46	4500	25.46	12.50
600	29.34	14.41	5000	25.00	12.28
800	29.13	14.31	5500	24.54	12.05
1000	28.93	14.21	6000	24.10	11.84
1500	28.41	13.95	6500	23.67	11.63

ALTITUDE AND ATMOSPHERIC PRESSURE

This table from the United States Weather Bureau gives altitudes and average atmospheric pressures.

Location	Elevation in feet above sea level	Average atmospheric pressure pounds	Location	Elevation in feet above sea level	Average atmospheric pressure pounds
Abilene, Tex.	1738	13.85	Hartford, Conn.	159	14.66
Albany, N. Y.	97	14.70	Helena, Mont.	4110	12.67
Amarillo, Tex.	3676	12.90	Houston, Tex.	138	14.68
Asheville, N. C.	2253	13.62	Indianapolis, Ind.	822	14.32
Altanta, Ga.	1173	14.16	Kansas City, Mo.	963	14.23
Atlantic City, N. J.	52	14.72	Keokuk, Iowa	614	14.42
Austin, Tex.	605	14.43	Knoxville, Tenn.	995	14.25
Baker, Ore.	3471	13.01	Lander, Wyo.	5372	12.10
Baltimore, Md.	123	14.69	Lincoln, Neb.	1189	14.11
Binghamton, N. Y.	871	14.29	Los Angeles, Cal.	338	14.55
Birmingham, Ala.	700	14.39	Louisville, Ky.	525	14.48
Bismarck, N. Dak.	1674	13.84	Madison, Wis.	974	14.23
Boise, Idaho	2739	13.35	Memphis, Tenn.	399	14.55
Boston, Mass.	125	14.67	Miami, Fla.	25	14.74
Brownsville, Tex.	57	14.69	Milwaukee, Wis.	681	14.38
Buffalo, N. Y.	767	14,33	Minneapolis, Minn.	918	14.23
Burlington, Vt.	403	14.51	Montgomery, Ala.	223	14.65
Cairo, Ill.	358	14.57	Nashville, Tenn.	546	14.48
Charleston, S. C.	48	14.74	New Orleans, La.	53	14.73
Charlotte, N. C.	779	14.36	New York, N. Y.	314	14.58
Chattanooga, Tenn.	762	14.37	North Platte, Neb.	2821	13.29
Cheyenne, Wyo.	6088	11.79	Oklahoma City, Okla.	1214	14.11
Chicago, Ill.	673	14.39	Omaha, Neb.	1105	14.16
Cincinnati, Ohio	627	14.43	Parkesburg, W. Va.	637	14.45
Cleveland, Ohio	762	14.34	Philadelphia, Pa.	114	14.70
Columbia, N. C.	784	14.34	Pittsburgh, Pa.	842	14.31
Columbus, Ohio	822	14.33	Pocatello, Idaho	4477	12.52
Concord, N. H.	289	14.57	Pueblo, Colo.	4685	12.42
Corpus Christi, Tex.	20	14.72	Rapid City, S. Dak.	3259	13.06
Dallas, Tex.	512	14.47	Reno, Neb.	4532	12.51
Dayton, Ohio	899	14.29	Rochester, N. Y.	523	14.46
Del Rio, Tex.	944	14.22	Roswell, N. Mex.	3566	12.95
Denver, Colo.	5292	12.14	Sacramento, Cal.	69	14.69
Des Moines, Iowa	861	14.29	St. Louis, Mo.	568	14.45
Detroit, Mich.	730	14.36	St. Paul, Minn.	837	14.25
Dodge City, Kan.	2509	13.46	Salt Lake City, Utah	4360	12.5
Dubuque, Iowa	700	14.37	San Antonio, Tex.	693	14.38
Duluth, Minn.	1133	14.12	San Diego, Cal.	87	14.68
Elkins, W. Va.	1947	13.77	San Francisco, Cal.	155	14.66
El Paso, Tex.	3778	12.86	Santa Fe, N. Mex.	7013	11.44
Erie, Pa.	714	14.37	Seattle, Wash.	125	14.69
Evansville, Ind.	431	14.53	Shreveport, La.	249	14.62
Fort Smith, Ark.	457	14.50	Spokane, Wash.	1929	13.74
Fort Wayne, Ind.	856	14.29	Syracuse, N. Y.	597	14.43
Fort Worth, Tex.	670	14.39	Toledo, Ohio	628	14.42
Grand Rapids, Mich.	707	14.37	Washington, D. C.	112	14.70
Harrisburg, Pa.	374	14.55	Yuma, Ariz.	141	14.61

MERCURY VACUUM—ABSOLUTE PRESSURE

Based on atmospheric pressure of 14.4 pounds and mercury at 32 degrees F.

Inches mercury vacuum	Inches mercury absolute	Pounds per square inch absolute	Inches mercury vacuum	Inches mercury absolute	Pounds per square inch absolute
1	28.32	13.91	16	13.32	6.54
2	27.32	13.42	17	12.32	6.05
3	26.32	12.93	18	11.32	5.56
4	25.32	12.44	19	10.32	5.07
5	24.32	11.94	20	9.32	4.58
6	23.32	11.45	21	8.32	4.09
7	22.32	10.96	22	7.32	3.59
8	21.32	10.47	23	6.32	3.10
9	20.32	9.98	24	5.32	2.61
	19.32	9.49	25	4.32	2.12
11	18.32	9.00	26	3.32	1.63
12	17.32	8.51	27	2.32	1.14
13	16.32	8.01	28	1.32	0.65
14	15.32	7.52	29	0.32	0.16
15	14.32	7.03	30	....	....

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REPORT OF COMMITTEE ON NATURAL GAS RESERVES AMERICAN GAS ASSOCIATION

The summary of proved recoverable reserves of natural gas and natural gas liquids of the United States, as of December 31, 1953, is as follows:

NATURAL GAS RESERVES

(Millions of cubic feet)

Total proved reserves as of December 31, 1952		199,716,225
Extensions and revisions of previous estimate	13,371,355	
New reserves discovered in 1953	7,081,661	
Net changes in "stored gas" during 1953	516 431	
Total proved reserves added and net changes in "stored gas" during 1953		20,969,447
Total proved reserves as of December 31, 1952 and additions during 1953		220,685,672
Deduct production during 1953		9,238,540
Total proved reserves of natural gas as of December 31, 1953		211,447,132

NATURAL GAS LIQUIDS RESERVES

(Thousands of barrels of 42 U. S. Gallons)

Total proved reserves as of December 31, 1952		4,996,651
Extensions and revisions of previous estimate	648,047	
New reserves discovered in 1953	95,922	
Total proved reserves added in 1953		743,969
Total proved reserves as of December 31, 1952 and new proved reserves added in 1953		5,740,620
Deduct production during 1953		302,698
Total proved reserves of natural gas liquids as of December 31, 1953		5,437,922

SUMMARY OF ANNUAL ESTIMATES OF NATURAL GAS RESERVES

December 31, 1945 to December 31, 1953

(Millions of Cubic Feet—14.65 psia, at 60 deg F)

Year	Natural Gas Added during Year: Extensions and Revisions	Natural Gas Added during Year: Discoveries of New Fields and New Pools in Old Fields	Natural Gas Added during Year: Total of Discoveries, Revisions and Extensions	Net Change in Storage	Net Production during Year	Estimated Proved Reserves as of End of Year	Increase over Previous Year
1945	.....	.....	.....	.....	.....	147,789,367	.....
1946	*	*	17,729,152	*	4,942,617	160,575,901	12,786,535
1947	7,570,654	3,410,170	10,980,824	*	5,629,811	165,926,914	5,351,013
1948	9,769,483	4,129,089	13,898,572	51,482	6,007,628	173,869,340	7,942,426
1949	8,061,429	4,612,870	12,674,299	82,746	6,245,041	180,381,344	6,512,004
1950	9,172,381	2,877,351	12,049,732	54,301	6,892,678	185,592,699	5,211,355
1951	13,013,606	3,039,385	16,052,991	132,751	7,966,941	193,811,500	8,218,801
1952	8,934,470	5,411,043	14,345,513	198,850	8,629,638	199,716,225	5,904,725
1953	13,371,355	7,081,661	20,453,016	516,431	9,238,540	211,447,132	11,730,907

*Not estimated.

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TOTAL GAS UTILITY SALES, BY TYPE OF GAS, 1932-1953

Note: Liquified petroleum gas data are included with manufactured gas prior to 1945. Excludes sales for resale.

(Millions of therms)

Year	Total	Type of Gas			
		Natural	Manufactured	Mixed	Liquified Petroleum
1932	10,441.3	8,190.0	1,731.1	520.2	
1933	10,530.6	8,373.8	1,579.8	577.0	
1934	12,063.4	9,831.6	1,609.9	621.9	
1935	12,923.9	10,635.1	1,610.5	678.3	
1936	14,692.9	12,356.1	1,594.2	742.6	
1937	15,773.4	13,480.0	1,535.2	758.2	
1938	14,681.6	12,422.8	1,525.8	733.0	
1939	15,926.8	13,576.2	1,580.4	770.2	
1940	17,235.4	14,681.4	1,688.1	865.9	
1941	19,009.3	16,358.3	1,725.6	925.4	
1942	20,848.7	17,970.1	1,848.4	1,030.2	
1943	23,414.7	20,324.6	1,967.1	1,123.0	
1944	25,119.8	21,941.0	2,034.9	1,143.9	
1945	25,867.7	22,562.8	2,087.5	1,194.2	23.2
1946	26,379.1	22,913.2	2,176.1	1,253.3	36.5
1947	29,882.4	26,021.5	2,319.2	1,481.4	60.3
1948	33,885.3	30,164.0	2,368.3	1,266.6	86.4
1949	35,789.7	32,233.9	2,274.0	1,190.9	90.9
1950	42,090.1	38,499.9	2,216.7	1,283.6	89.9
1951	48,221.8	44,718.3	1,763.0	1,652.4	88.1
1952	52,704.0	49,293.2	1,244.5	2,082.0	84.3
1953	56,466.8	53,194.3	836.7	2,351.4	84.4

TOTAL GAS UTILITY SALES, BY CLASS OF SERVICE, 1932-1953

Note: Excludes sales for resale.

(Millions of therms)

Year	Total	Residential	Commercial	Industrial	Other
1932	10,441.3	4,672.3	1,193.3	4,533.8	41.9
1933	10,530.6	4,237.2	1,150.3	5,113.8	29.3
1934	12,063.4	4,201.5	1,101.6	6,698.6	61.7
1935	12,923.9	4,444.5	1,211.1	7,220.9	47.4
1936	14,692.9	4,784.2	1,368.8	8,279.6	260.3
1937	15,773.4	4,987.3	1,381.5	9,041.1	363.5
1938	14,681.6	4,956.2	1,379.6	7,940.9	404.9
1939	15,926.8	5,289.4	1,468.5	8,768.3	400.6
1940	17,235.4	5,823.1	1,597.7	9,543.7	270.9
1941	19,009.3	5,862.0	1,649.5	11,206.0	291.8
1942	20,848.7	6,678.8	1,989.7	11,723.0	457.2
1943	23,414.7	7,001.4	2,083.1	13,582.4	747.8
1944	25,119.8	7,312.5	2,208.3	14,634.7	964.3
1945	25,867.7	7,749.3	2,497.3	14,523.3	1,097.8
1946	26,379.1	8,482.3	2,629.9	14,602.2	664.7
1947	29,882.4	10,086.5	3,106.7	15,791.8	897.4
1948	33,885.3	11,152.9	3,535.3	17,980.9	1,216.2
1949	35,790.4	11,827.9	3,724.4	18,978.5	1,259.6
1950	42,090.1	13,839.1	4,103.8	22,886.7	1,260.5
1951	48,221.8	16,204.5	4,559.4	25,521.9	1,936.0
1952	52,704.0	17,347.9	4,929.1	27,989.7	2,437.3
1953	56,466.8	18,037.4	4,982.0	30,389.5	3,057.9

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BELLAMY DEMAND-CHARGE RATE FORMULA
For All Load Factors

$$\text{Demand-charge per Mcf gas delivered} = \frac{3.288 \times DC}{LF}$$

where

DC = Demand-charge per Mcf of billing demand per month
LF = Load factor

Therefore,

$$\text{Price per Mcf of gas delivered} = \frac{3.288 \times DC}{LF} + \text{commodity charge}$$

Example:

(Assumed Gas Rate)
Demand charge = $2.10 per Mcf billing demand per month
Commodity charge = 21c per Mcf of gas delivered
To determine price of gas at 70 per cent load factor

Then

$$\text{Gas price per Mcf} = \frac{3.288 \times 210}{70} + 21 = 9.86 + 21 = 30.86c$$

SELECTED OPERATING STATISTICS OF MAJOR PIPE LINE SYSTEMS, 1953

Note: Includes pipe line systems with more than 500 miles of transmission mains and $5,000,000 operating revenues.

Name of Pipeline System	Compressor Stations		Miles of Transmission Mains				Maximum Daily Capacity (MMCF)	1953 Operating Revenues (000,000)
	No. of Stations	Installed Horse-power	Total	10" & Under Diameter	10.1–20.0" Diameter	20.1" & Over Diameter		
Algonquin Gas Transmission Co.	0	0	533	211	58	264	226	$ 3.1[b]
Atlantic Seaboard Corp.	9	41,925	741	56	425	260	470	38.1
Colorado Interstate Gas Co.	11	79,595	1,251	271	742	238	790	17.9
Cities Service Gas Co.	29	153,120	4,278	1,428	2,199	651	1,092[a]	46.3
East Tennessee Natural Gas Co.	0	0	573	125	279	169	237	12.1
El Paso Natural Gas Co.	59	584,980	5,706	1,307	1,591	2,808	1,910	111.1
Michigan-Wisconsin Pipeline Co.	16	161,080	1,592	370	64	1,158	766[a]	39.4
Mississippi River Fuel Co.	19	100,970	1,272	246	115	911	496[a]	38.4
Natural Gas Pipeline Co.-Chicago District Pipeline Co.	28	161,060	2,414	119	330	1,965	686[a]	34.8
New York State Natural Gas Corp.	11	72,500	1,294	137	1,156	1	706[a]	36.5
Northeastern Gas Transmission Co.	0	0	513	245	130	138	220	10.8
Northern Natural Gas Co.	23	343,880	5,213	1,612	1,536	2,065	1,091[a]	66.2
Olin Gas Transmission Corp.	2	20,100	848	125	475	248	426[a]	19.0
Panhandle Eastern Pipeline Co.	21	271,790	4,866	907	1,061	2,898	970	95.0
Southern Natural Gas Co.	19	155,900	3,759	709	2,046	1,004	860	48.3
Tennessee Gas Transmission Co.	26	483,380	6,555	380	792	5,383	1,479[a]	130.3
Texas Eastern Transmission Corp.	38	364,910	4,545	118	1,887	2,540	1,200	135.9
Texas Gas Transmission Co.	20	140,250	2,927	843	786	1,298	927[a]	60.8
Texas Illinois Natural Gas Pipeline Co.	11	130,000	1,495	8	239	1,248	504	34.1
Transcontinental Gas Pipeline Corp.	19	259,200	2,328	324	227	1,777	560	59.0
Trunkline Gas Co.	4	32,000	1,209	0	264	945	297[a]	22.2
United Gas Pipeline Co.	32	161,135	8,040	2,937	3,767	1,336	N.a.	157.6

a. Peak day delivery.
b. Represents part-year operation.

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DAILY CAPACITY OF GAS WELLS[1]

Open flow in cubic feet in 24 hours based on the following conditions: base and flowing temperature, 60 degrees F., base pressure, 14.65 pounds absolute (four ounces), specific gravity, 0.60.

Pressure by[2]			Diameter of opening—inches							
Water gage	Mercury gage	Pressure gage	1	2	3	4	5-5 3/16	6 1/4	6 5/8	8 1/4
Ins.	Ins.	PSI								
.1	...	...	12,000	48,000	108,000	192,000	300,000	453,600	507,000	783,360
.2	...	...	16,848	67,392	151,632	269,568	421,200	636,854	711,828	1,099,772
.3	...	...	20,760	83,040	186,840	332,160	519,000	784,728	877,110	1,355,212
.4	...	...	23,640	94,560	212,760	378,240	591,000	893,592	998,790	1,543,219
.5	...	...	26,448	105,792	238,032	423,168	661,200	999,734	1,117,428	1,726,525
.6	...	...	28,992	115,968	260,928	463,872	724,800	1,095,897	1,224,912	1,892,597
.7	...	...	31,560	126,240	284,040	504,960	789,000	1,192,968	1,301,850	2,062,368
.8	...	...	33,600	134,400	302,400	537,600	840,000	1,270,080	1,419,600	2,193,408
.9	...	...	35,760	143,040	321,840	572,160	894,000	1,351,728	1,510,860	2,334,412
1.	...	...	37,680	150,720	339,120	602,880	942,000	1,424,304	1,591,980	2,459,750
1.25	...	...	42,240	168,960	380,160	675,840	1,056,000	1,596,672	1,784,640	2,757,427
1.34	.1	...	44,040	176,160	396,360	704,640	1,101,000	1,664,712	1,860,690	2,874,931
1.5	.11	...	46,080	184,320	414,720	737,280	1,152,000	1,741,824	1,946,880	3,008,102
1.75	.13	...	49,800	199,200	448,200	796,800	1,245,000	1,882,440	2,104,050	3,250,944
2.	.15	...	53,280	213,120	479,520	852,480	1,332,000	2,013,984	2,251,080	3,478,118
2.5	.18	...	59,520	238,080	535,680	952,320	1,488,000	2,249,856	2,514,720	3,885,465
2.69	.2	...	62,160	248,640	559,440	994,560	1,554,000	2,349,648	2,626,260	4,057,804
3.	.22	...	65,160	260,640	586,440	1,042,560	1,629,000	2,463,048	2,753,010	4,253,644
3.5	.26	...	70,392	281,568	633,528	1,126,272	1,759,800	2,660,817	2,974,062	4,595,189
4.04	.3	...	76,080	304,320	684,720	1,217,280	1,902,000	2,875,824	3,214,380	4,966,502
4.5	.33	...	79,920	319,680	719,280	1,278,720	1,998,000	3,020,976	3,376,620	5,217,177
5.	.37	...	82,680	330,720	744,120	1,322,880	2,067,000	3,125,304	3,493,230	5,397,350
5.39	.4	...	87,720	350,880	789,480	1,403,520	2,193,000	3,315,816	3,706,170	5,726,361
6.	.44	...	92,160	368,640	829,440	1,474,560	2,304,000	3,483,648	3,893,760	6,016,204
6.74	.5	...	98,280	393,120	884,520	1,572,480	2,457,000	3,714,984	4,152,330	6,415,718
8.08	.6	...	107,760	431,040	969,840	1,724,160	2,694,000	4,073,328	4,552,860	7,034,572
9.	.66	...	113,040	452,160	1,017,360	1,808,640	2,826,000	4,272,912	4,770,940	7,379,251
9.43	.7	...	116,400	465,600	1,047,600	1,862,400	2,910,000	4,399,920	4,817,900	7,598,592
10.	.74	...	119,040	476,160	1,071,360	1,904,640	2,976,000	4,499,712	5,029,440	7,770,931
10.78	.8	...	124,320	497,280	1,118,880	1,989,120	3,108,000	4,699,296	5,252,520	8,115,609
12.	.88	...	130,320	521,280	1,172,880	2,085,120	3,258,000	4,926,096	5,516,020	8,507,289
12.13	.9	...	131,880	527,520	1,186,920	2,110,080	3,297,000	4,985,064	5,571,930	8,609,126
13.75	1.02	.50	138,600	554,400	1,247,400	2,217,600	3,465,000	5,239,080	5,856,850	9,047,808
20.22	1.5	.73	170,280	681,120	1,532,520	2,724,480	4,257,000	6,436,584	7,194,330	11,115,875
26.96	2.	.98	196,680	786,720	1,770,120	3,146,880	4,917,000	7,434,504	8,309,730	12,839,270
33.70	2.5	1.22	219,960	879,840	1,979,640	3,519,360	5,499,000	8,314,488	9,293,310	14,358,988
40.44	3.	1.47	240,720	962,880	2,166,480	3,851,520	6,018,000	9,099,216	10,170,420	15,714,201
47.18	3.5	1.71	259,920	1,039,680	2,339,280	4,158,720	6,498,000	9,824,970	10,981,620	16,967,577
53.92	4.	1.96	277,200	1,108,800	2,494,800	4,435,200	6,930,000	10,478,160	11,711,700	18,095,616
60.66	4.5	2.20	294,600	1,178,650	2,651,760	4,714,240	7,366,000	11,135,880	12,448,530	19,231,488
67.40	5.	2.45	310,800	1,243,200	2,797,200	4,972,800	7,770,000	11,748,240	13,131,300	20,289,024
74.14	5.5	2.69	325,800	1,303,200	2,932,200	5,212,800	8,145,000	12,315,240	13,765,050	21,268,224
80.88	6.	2.94	340,200	1,360,800	3,061,800	5,443,200	8,505,000	12,859,560	14,373,450	22,208,256
87.62	6.5	3.18	354,200	1,416,480	3,187,080	5,665,920	8,853,000	13,385,736	14,931,570	23,116,953
94.36	7.	3.43	367,680	1,470,720	3,309,120	5,882,880	9,192,000	13,898,304	15,533,480	24,002,150

DAILY CAPACITY OF GAS WELLS—Continued

Pressure by[2]			Diameter of opening—inches							
Water gage	Mercury gage	Pressure gage	1	2	3	4	5-5 3/16	6 1/4	6 5/8	8 1/4
Ins.	Ins.	PSI								
101.10	7.5	3.67	380,400	1,521,600	3,423,600	6,086,400	9,510,000	14,379,120	16,071,900	24,832,512
107.84	8.	3.92	392,880	1,571,520	3,535,920	6,286,080	9,822,000	14,850,864	16,599,180	25,647,206
114.58	8.5	4.16	405,000	1,620,000	3,645,000	6,480,000	10,125,000	15,309,000	17,111,250	26,438,400
121.32	9.	4.41	416,640	1,666,650	3,749,760	6,666,240	10,416,000	15,748,992	17,603,040	27,198,259
128.06	9.5	4.61	428,280	1,713,120	3,854,520	6,852,480	10,707,000	16,188,984	18,095,460	27,958,118
134.80	10.	4.90	439,920	1,759,680	3,959,280	7,038,720	10,998,000	16,604,784	18,586,620	28,717,977
164.46	12.2	6.	476,040	1,904,150	4,284,360	7,616,640	11,901,000	17,994,312	20,112,690	31,075,891
.....	14.23	7.	517,320	2,069,280	4,665,880	8,277,120	12,933,000	19,554,696	21,856,770	33,770,649
.....	16.26	8.	542,400	2,169,600	4,881,600	8,678,400	13,560,000	20,502,720	22,916,400	35,407,872
.....	18.30	9.	569,640	2,278,560	5,126,760	9,114,240	14,241,000	21,532,392	24,067,290	37,186,099
.....	20.33	10.	595,440	2,381,760	5,358,960	9,527,040	14,886,000	22,507,632	25,157,340	38,870,032
.....	22.36	11.	621,960	2,487,840	5,597,640	9,951,360	15,549,000	23,510,088	26,277,810	40,601,548
.....	24.39	12.	642,600	2,570,400	5,783,400	10,281,600	16,065,000	24,290,280	27,149,850	41,948,928
.....	26.43	13.	664,680	2,658,720	5,982,120	10,634,880	16,617,000	25,124,904	27,933,177	43,390,310
.....	28.46	14.	683,880	2,735,520	6,154,920	10,942,080	17,097,000	25,850,664	28,893,930	44,643,686
.....	30.50	15.	704,520	2,818,080	6,340,680	11,272,320	17,613,000	26,630,856	29,765,970	45,991,065
.....	32.53	16.	720,720	2,882,880	6,486,480	11,531,520	18,018,000	27,243,216	30,460,430	47,048,601
.....	36.60	18.	750,240	3,000,960	6,752,160	12,003,840	18,756,000	28,359,072	31,697,640	48,975,667
.....	40.66	20.	785,520	3,142,080	7,069,680	12,568,320	19,638,000	29,692,656	33,188,220	51,278,745
.....	44.73	22.	803,280	3,213,120	7,229,520	12,852,480	20,082,000	30,363,984	33,938,580	52,437,676
.....	50.81	25.	854,880	3,419,520	7,693,920	13,678,080	21,372,000	32,314,464	36,718,680	55,806,124
.....	61.00	30.	910,920	3,643,680	8,198,280	14,574,720	22,773,000	34,432,776	38,486,370	59,464,415
.....	71.16	35.	960,960	3,843,840	8,648,640	15,375,360	24,024,000	36,324,288	40,600,560	62,731,027
.....	81.33	40.	1,006,680	4,026,720	9,060,120	16,106,880	25,167,000	38,052,504	42,532,230	65,715,628
.....	91.50	45.	1,046,520	4,186,080	9,418,680	16,774,320	26,163,000	39,558,456	44,215,470	68,316,383
.....	....	50.	1,081,920	4,327,680	9,737,280	17,310,720	27,048,000	40,896,576	45,711,120	70,627,295
.....	....	60.	1,137,120	4,548,480	10,234,080	18,193,920	28,428,000	42,983,136	48,043,320	74,230,751
.....	....	75.	1,223,400	4,893,600	11,010,600	19,574,400	30,585,000	46,244,450	51,688,650	79,863,110
.....	....	90.	1,304,400	5,217,600	11,739,600	20,870,400	32,610,000	49,306,320	55,110,900	85,150,790
.....	....	100.	1,336,920	5,347,680	12,032,280	21,390,720	33,422,000	50,535,576	56,484,860	87,273,695
.....	....	110.	1,369,320	5,477,280	12,323,880	21,909,120	34,233,000	51,760,296	57,853,770	89,388,767
.....	....	120.	1,401,720	5,606,880	12,615,480	22,427,520	35,043,000	52,985,016	59,222,670	91,504,281

[1]Courtesy—Dresser Manufacturing Company.

[2]Pressure as measured with a Pitot tube inserted in the flowing gas just inside the pipe or tubing, between one-third and one-fourth of the pipe diameter from the outer edge, and with the plane of the opening in the tube held at right angles to the flowing gas. The top length of tubing or casing should be free from fittings for a distance of 10 feet below the mouth of the well when the test is made. The test should not be made in a collar or gate or at the mouth of any fitting. The well should be blown off for at least 3 hours prior to final reading, or until the readings do not decrease over a 15-minute period.

If the specific gravity of the gas is other than 0.60, multiply the flow by the square root of 0.60, divided by the specific gravity of the gas from the well being tested. For flowing temperatures above or below 60 degrees F., deduct or add 1 per cent for each 10 degrees, respectively.

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GAS FLOW FORMULAS

HIGH PRESSURE GAS FLOW

The Weymouth Formula. This is considered to be the best known and most widely used formula. The original formula is as follows:

$$Q = 433.5 \frac{T_o}{P_o} \left[\frac{(P_1^2 - P_2^2) d^{16/3}}{GTL} \right]^{1/2}$$

where

Q = flow cubic feet per day under standard conditions (P_o and T_o)
d = internal diameter of pipe, inches
T_o = standard absolute temperature °F
T = temperature of flowing gas—absolute °F
P_o = standard pressure, psia
P_1 = initial pressure, psia
P_2 = terminal pressure, psia
G = specific gravity of gas, air = 1.0
L = length of pipe line, miles

By assuming

$T_o = 60 + 460 = 520°$ F
$P_o = 14.73$ psia
$T = 50 + 460 = 510°$ F

the above formula is simplified to:

$$Q = 676.2 \sqrt{\frac{(P_1^2 - P_2^2)\, d^{16/3}}{GL}}$$

or

$$Q = 676.2\, d^{8/3} \sqrt{\frac{P_1^2 - P_2^2}{GL}}$$

The Weymouth formula with supercompressibility. When the Weymouth Formula for Flow of Gas in Pipe Lines was introduced before the A. S. M. E. in 1912, the maximum working pressures in pipe lines did not exceed 350 to 400 pounds per square inch and the effects of the deviation of actual gases from the ideal gas laws were not thought to be significant and were not recognized.

With the much higher pressures that have been adopted since that time it is necessary to incorporate into the original formula an allowance for supercompressibility of gases to make it applicable to present practice. This adjustment is rendered relatively simple by taking advantage of the fact that within the pressure range for which gas transmission lines are now designed, and at the average temperature of flowing gas usually encountered in practice, natural gas follows a deviation pattern which may be represented by a straight line supercompressibility function of the pressure of the form of $(1 + JP) = \frac{1}{Z}$. By utilizing this relationship, the modified General Formula becomes:

$$Q = 433.5 \frac{T_o}{P_o} \left[\frac{(P_1^2 - P_2^2) d^{5\,1/3}}{GTL} \right]^{1/2} (1 + JP_m)^{1/2} \qquad (1)$$

and since

$$P_m = 2/3 \left[P_1 + P_2 - \frac{P_1 P_2}{P_1 + P_2} \right]$$

this reduces to

$$Q = 433.5 \frac{T_o}{P_o} \frac{d^{8/3}}{\sqrt{GTL}} [P_1^2 (1 + 2/3\, JP_1) - P_2^2 (1 + 2/3\, JP_2)]^{1/2} \qquad (2)$$

In the above,

P_m = Mean pressure of line, psia
J = Factor for supercompressibility.
Z = Reciprocal of $(1 + JP)$
r = Ratio of compressions = $\frac{P_1}{P_2}$

A simplified working formula applicable to general design problems can be derived from the general formula by assuming values for T_o, P_o, G and T which will approximate those to be anticipated in most cases and combining them into a constant, K, thus,

$$K = 433.5 \frac{T_o}{P_o \sqrt{GT}}.$$

The factor J may also be assumed at a constant value that will apply to the majority of cases without serious error.

By using the following values:

$T_o = 60 + 460 = 520$ deg. F
$P_o = 14.73$ psia (30" Hg.)
$G = 0.65$
$T = 50 + 460 = 510$ deg. F
$J = 0.00022$ per 1 psia

the value of K will be 840.5 and the working formula will be

$$Q = 840.5 \frac{d^{8/3}}{\sqrt{L}} [P_1^2 (1 + 0.000147\, P_1) - P_2^2 (1 + 0.000147\, P_2)]^{1/2} \qquad (3)$$

For conditions other than those assumed above, K can be modified by multiplying by such of the following factors as is appropriate:

$$\frac{T_o}{520};\quad \frac{14.73}{P_o};\quad \sqrt{\frac{0.65}{G}};\quad \sqrt{\frac{510}{T}}.$$

If P_1 and P_2 are known, the simplest form of the formula in solving for Q, d or L is found by utilizing the ratio of compressions, $r = \frac{P_1}{P_2}$, thus:

$$Q = K \frac{d^{8/3}}{\sqrt{L}} P_2 [(r^2 - 1) + 2/3\, JP_2 (r^3 - 1)]^{1/2} \qquad (4)$$

The simplest method of solving for P_1 or P_2 is as follows:

1st. From equation (2) or (3), solve for the value of the parenthetical term under the radical which contains the unknown pressure, $P^2 (1 + 2/3\, JP)$. Call this C.

2nd. Select a trial pressure, P_a, preferably the round figure value nearest to the square root of C.

3rd. Solve for $C_a = P_a^2 (1 + 2/3\, JP_a)$.

4th. Select a second trial pressure, P_b, preferably a round figure nearest to the square root of .8C to .85C, and solve for $C_b = P_b^2 (1 + 2/3\, JP_b)$.

5th. Solve for the unknown P from

$$P = P_b + \frac{C - C_b}{C_a - C_b} (P_a - P_b)$$

being sure to do it algebraically, in case the selection of P_b should make C_b greater than C.

These computations are easily and quickly made on the slide rule with sufficient accuracy to satisfy most design problems encountered in practice, and within the range of precision fixed by other factors involved.

A line composed of several lengths L_1, L_2, etc., of diameters d_1, d_2, etc., can be transformed into a single equivalent line of uniform diameter d_o, by determining the equivalent length of each individual section by means of the formula $L_{o,1} = L_1 \left(\frac{d_o}{d_1} \right)^{5\,1/3}$ and adding these equivalent section lengths together to form an equivalent line of diameter d_o and total length L_o.

To transform a length of pipe of diameter d and length L, to a pipe of equivalent capacity having a length L_o, the diameter of the equivalent section will be $d_o = d \left(\frac{L_o}{L} \right)^{3/16}$.

The diameter of a single pipe having a capacity equivalent to the aggregate capacity of several parallel, or looped lines of a common length and of diameters d_1, d_2, etc., is equal to

$$d_o = [d_1^{8/3} + d_2^{8/3} + \text{— etc.,}]^{3/8} = [\Sigma\, d^{8/3}]^{3/8}.$$

If the several loops have different lengths, the actual diameters of the loops must first be transformed into equivalent diameters of pipe having a common length, and these equivalent diameters then be added in accordance with the formula just given.

For general office use the formula can be still further simplified by combining the K and d factors into a single constant, $A = Kd^{8/3}$, and using a table of values of A for the principal sizes and weights of pipe in common use. Table 1 gives values of A for the constants assumed above and for pipes up to and including 30 inches outside diameter. Equation (3) then becomes:

$$Q = \frac{A}{\sqrt{L}}[P_1^2 (1 + 0.000147 P_1) - P_2^2 (1 + 0.000147 P_2)]^{1/2} \quad (5)$$

TABLE NO. 1

"A" FACTORS

Size (Inches)		Wall Thickness (Inches)	Internal Diameter (Inches)	"A"
1	(Nominal)	.133	1.049	954.6
1½	"	.145	1.610	2,992.
2	"	.154	2.067	5,826.
3	"	.216	3.068	16,700.
4	"	.237	4.026	34,470.
5-3/16	"	.304	4.892	57,950.
6	"	.280	6.065	102,800.
6⅝	"	.275	6.450	121,100.
8	"	.322	7.981	213,800.
8	"	.277	8.071	220,200.
8⅝	(O.D.)	.250	8.125	224,200.
10	(I.D.)	.365	10.020	392,100.
10¾	(O.D.)	.3125	10.125	403,200.
10¾	(O.D.)	.250	10.250	415,200.
12	"	.375	11.250	534,000.
12	"	.250	11.500	566,200.
12¾	"	.375	12.000	634,200.
12¾	"	.3125	12.125	652,000.
12¾	"	.250	12.250	670,100.
14	"	.375	13.250	826,000.
14	"	.3125	13.375	847,000.
14	"	.250	13.500	868,300.
16	"	.375	15.250	1,202,000.
16	"	.3125	15.375	1,224,000.
16	"	.250	15.500	1,255,000.
18	"	.375	17.250	1,669,000.
18	"	.3125	17.375	1,701,000.
18	"	.250	17.500	1,735,000.
20	"	.375	19.250	2,237,000.
20	"	.3125	19.375	2,275,000.
20	"	.250	19.500	2,314,000.
22	"	.375	21.250	2,911,000.
22	"	.3125	21.375	2,957,000.
24	"	.375	23.250	3,700,000.
24	"	.3125	23.375	3,753,000.
26	"	.375	25.250	4,611,000.
26	"	.3125	25.375	4,672,000.
28	"	.375	27.250	5,650,000.
28	"	.3125	27.375	5,720,000.
30	"	.375	29.250	6,825,000.
30	"	.3125	29.375	6,903,000.

FORMULA FOR DETERMINING MEAN PRESSURE (P_M) IN PIPE LINE

$$P_M = \tfrac{2}{3}\left(P_1 + P_2 - \frac{P_1 P_2}{P_1 + P_2}\right)$$

SUPERCOMPRESSIBILITY FACTOR

If a flow formula, which does not reflect the deviation from the ideal gas law, is used for problems involving pressures above 200 lbs., its results may be corrected by applying the following supercompressibility factor

$$\text{Supercompressibility Factor} = \sqrt{1 + .0002 P_M}$$

Values of $(d)^{8/3}$ and $(d)^{16/3}$

(Note — $d^{8/3} = \sqrt{d^{16/3}}$)

Diameter (d), inches			
External	Internal	$(d)^{8/3}$	$(d)^{16/3}$
2.375	2.067	6.933	48.063
3.500	3.068	19.87	394.99
4.500	4.026	41.02	1,682.6
6.625	6.040	121.0	14,640
6.625	6.125	125.6	15,773
6.625	6.250	132.5	17,567
8.625	8.071	262.1	68.700
8.625	8.125	266.8	71,182
8.625	8.185	272.1	74,035
10.000	9.625	419.2	175,710
10.750	10.192	488.3	238,440
10.750	10.250	495.7	245,760
12.750	12.090	770.0	592,870
12.750	12.188	786.7	618,920
12.750	12.250	797.5	635,930
14.000	13.500	1033.3	1,067,600
15.000	14.500	1250.2	1,563,000
16.000	15.250	1430.2	2,045,400
16.000	15.375	1461.7	2,136,500
16.000	15.500	1493.5	2,230,600
18.000	17.250	1986.6	3,946,500
18.000	17.375	2025.3	4,101,600
18.000	17.500	2064.3	4,261,400
20.000	19.250	2661.6	7,084,200
20.000	19.375	2707.9	7,333,000
20.000	19.432	2729.3	7,449,200
22.000	21.125	3410.4	11,631,000
22.000	21.375	3519.1	12,384,000
22.000	21.500	3574.1	12,775,000
24.000	23.125	4340.8	18,843,000
24.000	23.375	4466.8	19,953,000
24.000	23.500	4531.0	20,529,000
26.000	25.125	5415.4	29,326,000
26.000	25.500	5633.4	31,736,000
28.000	27.125	6642.3	44,120,000
28.000	27.500	6889.8	47,471,000
30.000	29.125	8030.0	64,482,000
30.000	29.500	8308.3	69,030,000

PANHANDLE FORMULA

This formula is used by many companies for the calculation of gas flow in large diameter (twelve inch and larger) transmission lines.

BASIC PANHANDLE FORMULA

$$Q = 435.87 e \left(\frac{T_o}{P_o}\right)^{1.07881} \left(\frac{(P_1^2 - P_2^2)}{G^{0.8539} T_f L}\right)^{0.5394} d^{2.6182}$$

Substituting:

T_o = Base temperature = 60° + 460° = 520° abs
P_o = Base pressure = 14.73 psia
T_f = Flowing temperature = 50° + 460° = 510° abs
G = Gravity of gas = 0.686 (Panhandle gas)

and where:

P_1 = Initial pressure—psia
P_2 = Final pressure—psia
L = Length of line in miles
d = Diameter of pipe in inches
e = Experience factor

the equation can be resolved to:

$$Q/d^{2.6182} = 839.51 e \left(\frac{(P_1^2 - P_2^2)}{L}\right)^{0.5394}$$

$$Q = \frac{80.8}{\rho_o \mu^{0.0814}} \left[\frac{D^{4.85} M (P_1^{-2} P_2^2)}{L Z_{av} T} \right]^{0.541} E,$$

where Q = Quantity of gas transported in cubic feet per day measured at P_o and T_o

ρ_o = Density of gas, pounds per cubic foot at P_o and T_o

μ = Absolute viscosity of gas, pounds per foot-second.

D = Inside diameter of pipe, inches.

M = Molecular weight of gas, pounds per mole.

P_1 = Discharge pressure from compressors, lbs. per sq. in. abs.

P_2 = Suction pressure to compressors, lbs. per sq. in. abs.

L = Distance between compressor stations, miles.

Z_{av} = Average deviation factor.

T = Flowing temperature, °R.

E = Experience factor for adjustment of formula.

For any gas line which is normally handling the same type of fluid at approximately constant temperature, the equation may be simplified by combining into a single term the expression for the gas density, the gas viscosity, molecular weight, temperature, and the numerical constant. Under normal conditions, the viscosity term will not influence the results greatly because a 30% change in absolute value of the viscosity will cause only about 2.7% change in the computed quantity of gas flowing. Thus, once the gas viscosity is determined for an operating line, small variations from the conditions under which it was determined will not influence the accuracy of the equation appreciably. The condensed form of the equation is then:

$$Q = K_2 \left[\frac{D^{4.85} P_1^2 (1 - 1/Cr^2)}{L Z_{av}} \right]^{0.541} E,$$

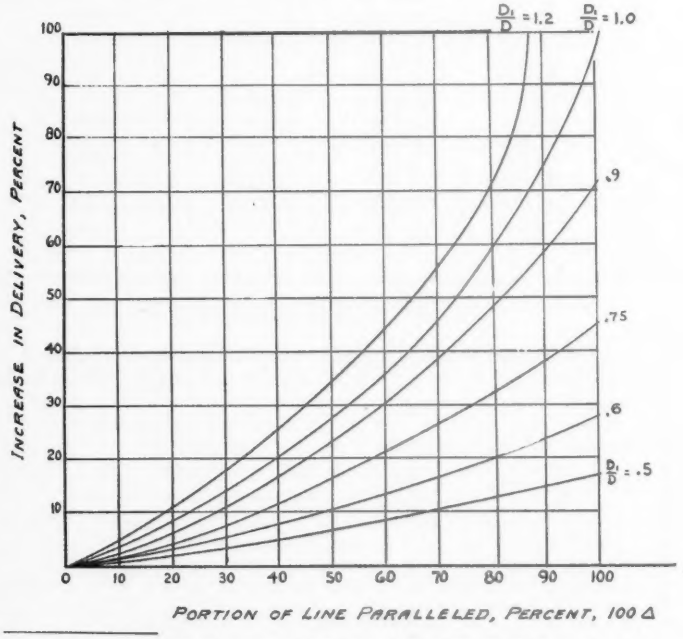
where $K_2 = \frac{80.8}{\rho_o \mu^{0.0814}} \left[\frac{M}{T} \right]^{0.541}$,

and Cr = Compression ratio, P_1/P_2.

"High Pressure Pipe Line Research." Copyright 1942, Clark Bros. Co., Inc.

RELATIONSHIP BETWEEN PERCENTAGE INCREASE IN THE DELIVERY AND PERCENTAGE OF THE LINE PARALLELED FOR DIFFERENT VALUES OF $\frac{D_1}{D}$

D_1 = Internal diameter of parallel line
D = Internal diameter of original line


INCREASE IN DELIVERY, PERCENT
PORTION OF LINE PARALLELED, PERCENT, 100 Δ
D1/D = 1.2
D1/D = 1.0
.9
.75
.6
D1/D = .5
0 10 20 30 40 50 60 70 80 90 100
10 20 30 40 50 60 70 80 90 100

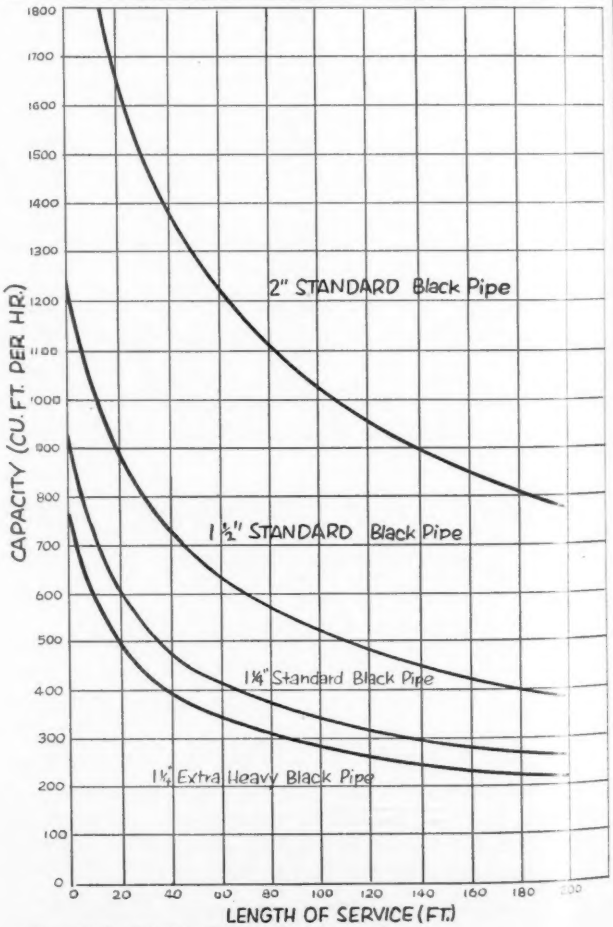
"High Pressure Pipe Line Research." Copyright 1942, Clark Bros. Co., Inc.

GUIDE FOR DETERMINING SERVICE LINE SIZES

Based on a pressure drop of ½" water column, from the main to the outlet end of the customer service line. Specific gravity of gas 0.65.

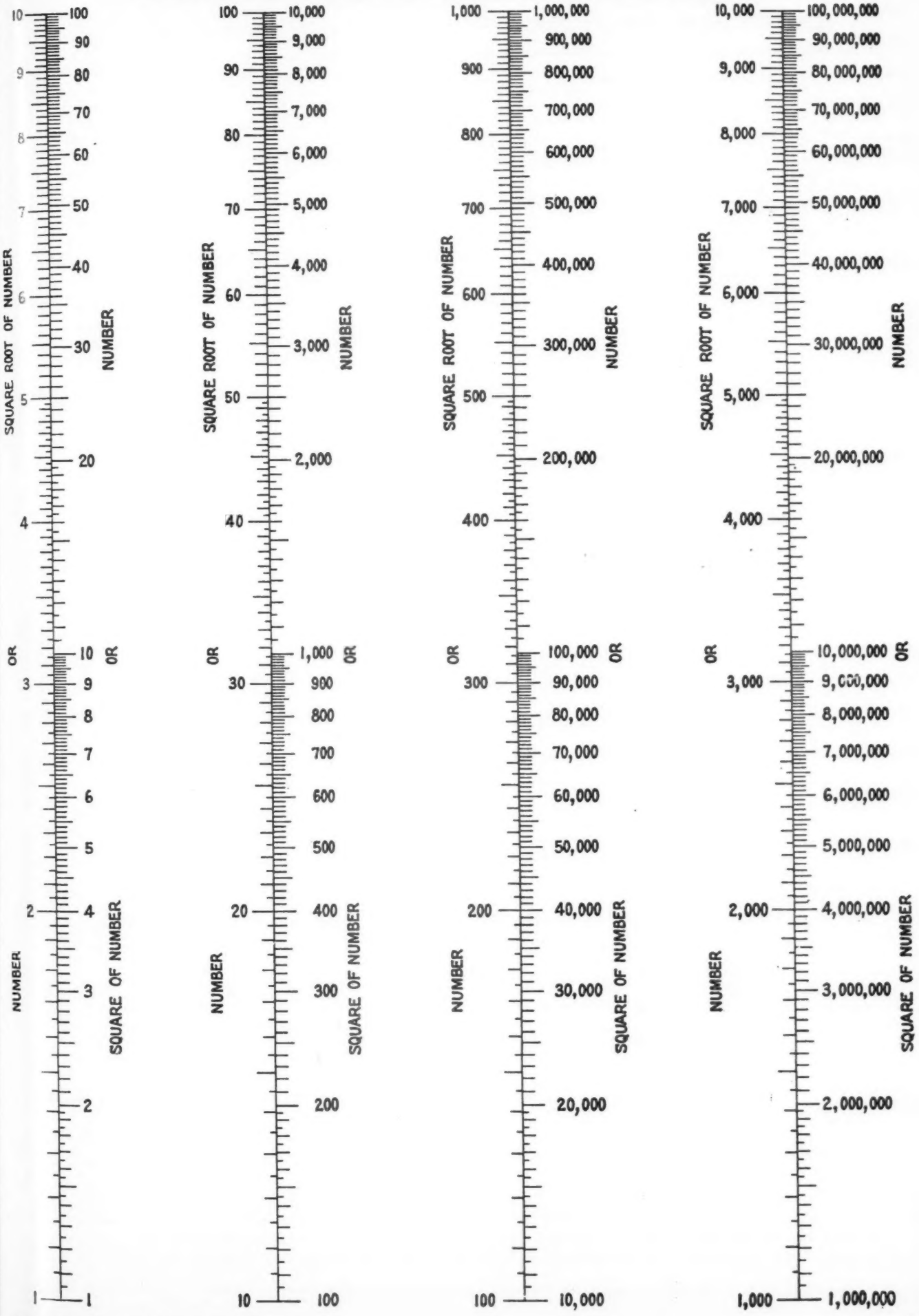
The length of service includes allowances for one tap opening, street tee, street ell, and stop cock.

Equivalent Footage Allowed			
Size Service	1¼"	1½"	2"
Tap Opening	2	2.5	3
Street Tee	7.5	9	12
Street Ell	4	5	6
Stop Cock	3	3.5	4
Total	16.5	20.0	25.0


CAPACITY (CU. FT. PER HR.)
LENGTH OF SERVICE (FT.)
2" STANDARD Black Pipe
1½" STANDARD Black Pipe
1¼" Standard Black Pipe
1¼" Extra Heavy Black Pipe
0 20 40 60 80 100 120 140 160 180
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800

From Columbia Gas System Engineering Corp.

CONVERSION CHART FOR DETERMINING SQUARES AND SQUARE ROOTS OF NUMBERS



LOW PRESSURE GAS FLOW

For distribution system problems the Spitzglass formulas are:

FOR PRESSURES NOT EXCEEDING ONE POUND GAUGE:

$$Q = 3550\,K\left(\frac{h}{S\,L}\right)^{1/2}$$

Where:

Q = Flow per hour in cubic feet of gas at 14.73 psi absolute (30" Hg.) and 60° F.
H = Pressure drop in inches of water column.
S = Specific gravity of gas. Air = 1.0
L = Length of pipe in feet.
d = Internal diameter of pipe in inches.

$$K = \left(\frac{d^5}{1 + \frac{3.6}{d} + 0.03d}\right)^{1/2}$$

FOR PRESSURES EXCEEDING ONE POUND GAUGE:

$$Q = 4830\,K\left(\frac{Pa}{SL}\right)^{1/2}$$

Where:

Q = Flow per hour in cubic feet of gas at 14.73 psi absolute (30" Hg.) and 60° F.
P = Pressure drop between pipe terminals in pounds per square inch.
a = Average pressure in pipe line, pounds per square inch absolute. (Absolute initial pressure minus half the pressure drop.)
S = Specific gravity of gas. Air = 1.0
L = Length of pipe in feet.
d = Internal diameter of pipe in inches.

$$K = \left(\frac{d^5}{1 + \frac{3.6}{d} + 0.03d}\right)^{1/2}$$

Values of $\sqrt{d^5}$

Diameter (d) Inches (Internal)	$\sqrt{d^5}$
.75	.4871
.824 (¾" Pipe)	.6163
1.000	1.000
1.049 (1" Pipe)	1.127
1.38 (1¼" Pipe)	2.237
1.50	2.756
1.61 (1½" Pipe)	3.289
2.00	5.657
2.067 (2" Pipe)	6.143
2.469 (2½" Pipe)	9.579
3.00	15.59
3.068	16.49
4.00	32.00
4.026	32.52
6.00	88.18
8.00	181.0
10.00	316.2
12.00	498.8
16.00	1024.
20.00	1789.
24.00	2822.
30.00	4930.
36.00	7776.

EQUIVALENT LENGTHS OF PIPE FITTINGS AND VALVES

Listed below are the lengths (in feet) of standard pipe which produce the same pressure drop as the fitting named in the left hand column

Type of fitting or valve	Nominal pipe size in inches																		
	½	¾	1	1¼	1½	2	2½	3	4	6	8	10	12	14 O.D.	16 O.D.	18 O.D.	20 O.D.	24 O.D.	30 O.D.
Standard tee with entry or discharge through side	3.4	4.5	5.5	7.5	9.0	12	14	17	22	33	43	55	65	78	85	105	115	135	170
Standard elbow or run[a] of tee reduced ½[b]	1.7	2.2	2.7	3.7	4.3	5.5	6.5	8	12	16	20	26	31	36	42	47	52	64	80
Medium sweep elbow or run[a] of tee reduced ¼[b]	1.3	1.8	2.3	3.0	3.7	4.6	5.4	6.8	9.0	14	18	22	26	30	35	40	43	55	67
Long sweep elbow or run[a] of standard tee or butterfly valve	1	1.3	1.7	2.3	2.7	3.5	4.2	5.3	7	11	14	17	20	23	26	31	34	41	52
45° Elbow	.8	1.0	1.2	1.6	2.0	2.5	3.0	3.7	5.0	7.5	10	12	15	17	20	22	24	30	37
Close return bend	3.7	5.1	6.2	8.5	10	13	15	19	24	37	49	62	75	86	100	110	125	150	185
Globe valve, wide open	16	22	27	40	43	45	65	82	120	170	240	290	340	400	440	500	550	680	850
Angle valve, wide open	8.2	11	14	18	21	28	33	42	56	85	112	145	165	190	220	250	280	340	420
Swing check valve, wide open	4.0	5.2	6.6	9.0	11	14	16	19	26	39	52	66	78	92	106	120	130	145	160
Gate valve, wide open, or slight bushing reduction	0.4	0.5	0.6	0.8	0.9	1.2	1.3	1.7	2.3	3.5	4.5	5.7	6.7	8.0	9.0	11	12	14	17

[a] A fluid is said to flow through the *run* of a tee when the flow is straight through the tee with no change of direction.

[b] A tee is said to be *reduced* ¼ if the internal area of the smaller connecting pipe is twenty-five per cent less than the internal area of the larger connecting pipe.

"North American Combustion Handbook." Copyright 1952, The North American Manufacturing Co.

WATER VAPOR IN SATURATED GAS

Per cent by volume, calculated from the gas laws

Temperature, °F.	Pressure, Pounds per Square Inch Absolute										
	50	100	150	200	250	300	350	400	500	600	700
40	0.244	0.122	0.081	0.061	0.049	0.041	0.035	0.030	0.024	0.020	0.017
50	0.356	0.178	0.119	0.089	0.071	0.059	0.051	0.044	0.036	0.030	0.025
60	0.512	0.256	0.171	0.128	0.102	0.085	0.073	0.064	0.051	0.043	0.037
70	0.726	0.363	0.242	0.181	0.145	0.121	0.104	0.091	0.073	0.061	0.052
80	1.014	0.507	0.338	0.253	0.203	0.169	0.145	0.127	0.101	0.084	0.072
90	1.396	0.698	0.465	0.349	0.279	0.233	0.199	0.174	0.140	0.116	0.100
100	1.898	0.949	0.633	0.474	0.380	0.316	0.271	0.237	0.190	0.158	0.136

From "Fuel Flue Gases." Copyright 1940. American Gas Association.

GALLONS OF WATER PER MILLION CUBIC FEET OF GAS

Pressure and temperature bases: 14.4 pounds per square inch and 60° F
Gas saturated with water vapor at indicated pressures and temperatures

Temperature, °F.	Pressure, Pounds per Square Inch Absolute										
	50	100	150	200	250	300	350	400	500	600	700
40	13.6	6.8	4.5	3.4	2.7	2.3	2.0	1.7	1.4	1.1	1.0
50	19.9	10.0	6.6	5.0	4.0	3.3	2.8	2.5	2.0	1.7	1.4
60	28.6	14.3	9.5	7.2	5.7	4.8	4.1	3.6	2.9	2.4	2.0
70	40.5	20.2	13.5	10.1	8.1	6.8	5.8	5.1	4.0	3.4	2.9
80	56.4	28.2	18.8	14.1	11.3	9.4	8.1	7.0	5.6	4.7	4.0
90	78.0	39.0	26.0	19.5	15.6	13.0	11.1	9.7	7.8	6.5	5.6
100	106.2	53.1	35.4	26.5	21.2	17.7	15.2	13.3	10.6	8.9	7.6

From "Fuel Flue Gases." Copyright 1940. American Gas Association.

VAPOR PRESSURE OF WATER

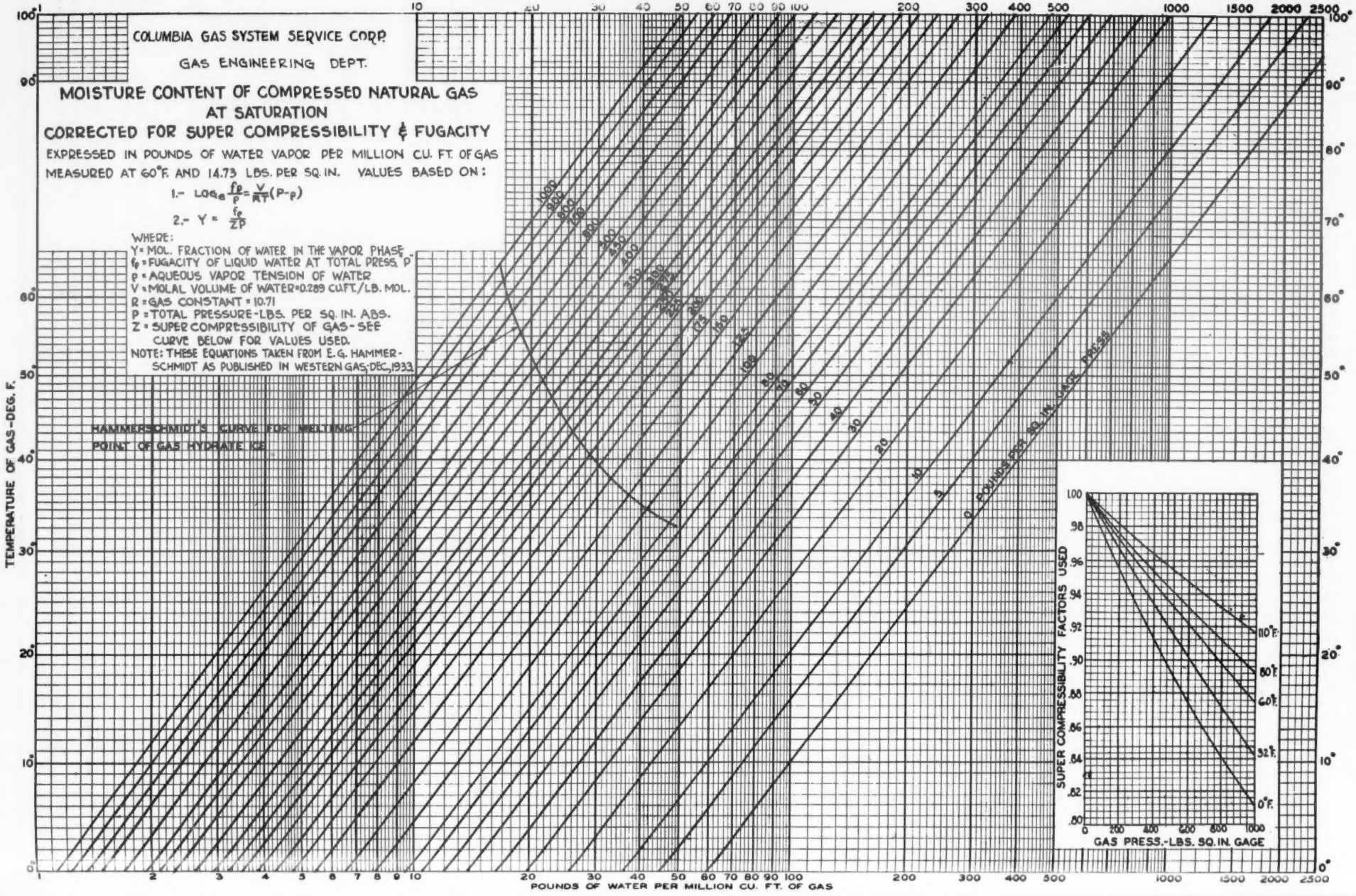
°F.	In. Hg	Lbs. per Sq. In. Absolute	°F.	In. Hg	Lbs. per Sq. In. Absolute	°F.	In. Hg	Lbs. per Sq. In. Absolute	°F.	In. Hg	Lbs. per Sq. In. Absolute
32	0.1803	0.08854	57	0.4686	0.2302	82	1.1016	0.5410	107	2.3786	1.1683
33	0.1878	0.09223	58	0.4858	0.2386	83	1.1378	0.5588	108	2.4491	1.2029
34	0.1955	0.09603	59	0.5035	0.2473	84	1.1750	0.5771	109	2.5214	1.2384
35	0.2035	0.09995	60	0.5218	0.2563	85	1.2133	0.5959	110	2.5955	1.2748
36	0.2118	0.10401	61	0.5407	0.2655	86	1.2527	0.6152	115	2.9948	1.4709
37	0.2203	0.10821	62	0.5601	0.2751	87	1.2931	0.6351	120	3.4458	1.6924
38	0.2292	0.11256	63	0.5802	0.2850	88	1.3347	0.6556	125	3.9539	1.9420
39	0.2383	0.11705	64	0.6009	0.2951	89	1.3775	0.6766	130	4.5251	2.2225
40	0.2478	0.12170	65	0.6222	0.3056	90	1.4215	0.6982	135	5.1653	2.5370
41	0.2576	0.12652	36	0.6442	0.3164	91	1.4667	0.7204	140	5.8812	2.8886
42	0.2677	0.13150	67	0.6669	0.3276	92	1.5131	0.7432	145	6.680	3.281
43	0.2782	0.13665	68	0.6903	0.3390	93	1.5608	0.7666	150	7.569	3.718
44	0.2891	0.14199	69	0.7144	0.3509	94	1.6097	0.7906	155	8.557	4.203
45	0.3004	0.14752	70	0.7392	0.3631	95	1.6600	0.8153	160	9.652	4.741
46	0.3120	0.15323	71	0.7648	0.3756	96	1.7117	0.8407	165	10.863	5.335
47	0.3240	0.15914	72	0.7912	0.3886	97	1.7647	0.8668	170	12.199	5.992
48	0.3364	0.16525	73	0.8183	0.4019	98	1.8192	0.8935	175	13.671	6.715
49	0.3493	0.17157	74	0.8462	0.4156	99	1.8751	0.9210	180	15.291	7.510
50	0.3626	0.17811	75	0.8750	0.4298	100	1.9325	0.9492	185	17.068	8.383
51	0.3764	0.18486	76	0.9046	0.4443	101	1.9915	0.9781	190	19.014	9.339
52	0.3906	0.19182	77	0.9352	0.4593	102	2.0519	1.0078	195	21.144	10.385
53	0.4052	0.19900	78	0.9666	0.4747	103	2.1138	1.0382	200	23.467	11.526
54	0.4203	0.20642	79	0.9989	0.4906	104	2.1775	1.0695	205	26.003	12.772
55	0.4359	0.2141	80	1.0321	0.5069	105	2.2429	1.1016	210	28.755	14.123
56	0.4520	0.2220	81	1.0664	0.5237	106	2.3099	1.1345	212	29.922	14.696

From "Fuel Flue Gases." Copyright 1940. American Gas Association.

A special case of partial pressure is that due to vapor pressures of substances at or near their condensing conditions, especially when in the presence of some liquids. The kinetic theory has shown how separation of molecules will permit the evaporation of other gaseous molecules into the same space. All liquids exposed to an available space will partially change to vapor. The partial pressure of this vapor in the space above the liquid is given the name "vapor pressure." For each temperature of the liquid, there is a corresponding vapor pressure. When the vapor pressure equals the external pressure, the liquid is at its boiling point. For water under pressure of one atmosphere, 212° F is the temperature at which this phenomenon takes place.

MOISTURE CONTENT OF COMPRESSED NATURAL GAS

CORRECTED FOR SUPERCOMPRESSIBILITY AND FUGACITY


COLUMBIA GAS SYSTEM SERVICE CORP.
GAS ENGINEERING DEPT.
MOISTURE CONTENT OF COMPRESSED NATURAL GAS
AT SATURATION
CORRECTED FOR SUPER COMPRESSIBILITY & FUGACITY
EXPRESSED IN POUNDS OF WATER VAPOR PER MILLION CU. FT. OF GAS MEASURED AT 60°F. AND 14.73 LBS. PER SQ. IN. VALUES BASED ON:
1.- $\log_e \frac{f_p}{p} = \frac{V}{RT}(P-p)$
2.- $Y = \frac{f_p}{ZP}$
WHERE:
Y = MOL. FRACTION OF WATER IN THE VAPOR PHASE.
f_p = FUGACITY OF LIQUID WATER AT TOTAL PRESS. P
p = AQUEOUS VAPOR TENSION OF WATER
V = MOLAL VOLUME OF WATER = 0.289 CU.FT./LB. MOL.
R = GAS CONSTANT = 10.71
P = TOTAL PRESSURE-LBS. PER SQ. IN. ABS.
Z = SUPER COMPRESSIBILITY OF GAS - SEE CURVE BELOW FOR VALUES USED.
NOTE: THESE EQUATIONS TAKEN FROM E.G. HAMMERSCHMIDT AS PUBLISHED IN WESTERN GAS, DEC., 1933
HAMMERSCHMIDT'S CURVE FOR MELTING POINT OF GAS HYDRATE ICE
TEMPERATURE OF GAS-DEG. F.
POUNDS OF WATER PER MILLION CU. FT. OF GAS
0 POUNDS PER SQ. IN. GAUGE PRESS.
SUPER COMPRESSIBILITY FACTORS USED
GAS PRESS.-LBS. SQ. IN. GAGE
110°F.
80°F.
60°F.
32°F.
0°F.

COMPARISON OF DRYING AGENTS AND DEHYDRATION PROCESSES*

Type of dehydration	Advantages	Disadvantages	Remarks
Physical and physicochemical methods: Cooling	Inexpensive where cooling water is cheap or refrigeration is available as by-product of another process	Limited degree of dehydration. Possibility of plugging cooler tubes with ice or hydrates	
Compression		Possibility of hydrate formations in cooler. Not economical unless higher pressures are necessary for some other step in processing the gas	Dehydration plants follow compressors to take advantage of this effect
Absorption			
With liquids			
Brine (35–40% $CaCl_2$)	$CaCl_2$ very cheap. Small make-up required (0.1–0.2 lb $CaCl_2$/million cu ft, 0.393 lb/million cu ft)	Danger of electrolytic corrosion (not corrosive in natural gas unless pH is below 4.2). Tends to emulsify with accumulated absorption oil, entrained oil, etc., to decrease the efficiency of contacting equipment. Available dew-point depression limited by the solubility of $CaCl_2$. Hydrogen sulfide forms objectionable precipitates	Dew-point depression of 23–31° F
Diethylene glycol 96%	Relatively stable toward gases containing oxygen, sulfur, or carbon dioxide. Good dew-point depression. No danger of solidification of concentrated solutions	0.2–0.8 lb glycol lost/million cu ft through vaporization	Dew-point depression of 40–60° F
Lithium chloride	Highly hygroscopic. Nontoxic. Not hydrolyzed on boiling. Concentrated solutions not readily solidified. Less corrosive than $CaCl_2$.	Expensive. Commercial grades of lithium chloride reported to be corrosive because of impurities	Dew-point depression of 40–67° F
Glycerin 85%		Expensive. Tends to decompose on regeneration. At concentrations above 85%, it becomes too viscous for easy handling and foams easily	Dew-point depression of 30–33° F. Used in manufactured gas plants abroad
Zinc chloride	High dew-point depression	Possible acid corrosion	Dew-point depression of 40–55° F
Calcium chloride, 40%. Glycerin 20%	Inhibits crystallization of $CaCl_2$, allowing greater dew-point depression than straight $CaCl_2$	Hydrogen sulfide forms iron sulfide and causes foaming. Corrosive	Dew-point depression of 23–41° F. 0.02 to 0.06 gal of make-up/million cu ft on unit treating 110–130 million cu ft/day at 200 psi
Dow 8A ($CaBr_2$-$CaCl_2$ and/or $CaBr_2$)	High dew-point depression	Corrosive	Dew-point depression of 29–64° F
Amine, glycol, water, 7–8% monoethanolamine, 75–80% diethylene glycol, 12–16% water	Simultaneous removal of water, carbon dioxide, hydrogen sulfide, and other acid gases. Greater dew-point depression than glycol alone. Glycol reduces foaming tendencies of the amine	Amines volatilize and may be adsorbed on solid desiccants used in subsequent processing, necessitating occasional washing of the desiccant	Approximately 0.1 gal/million cu ft make-up required
With solids			
Lump $CaCl_2$. Molded from water, $CaCl_2$ and pulverized minerals or molten 72% $CaCl_2$ solution. Addition of pulverized carbon adds odor adsorption	Inexpensive. High capacity. Simple equipment required	Disintegrates in water, obstructing gas flow. Corrosive. Efficiency of dehydration varies with amount of water absorbed. Generally discarded when once exhausted	
Lump KOH, NaOH (same advantages and disadvantages as lump $CaCl_2$)			Used for liquefied petroleum gases
Adsorption. Granular adsorbents in general (silica gel, activated alumina, activated $CaSO_4$, activated bauxite, Florite Desiccant)	Good drying efficiency. Not corrosive. Easily regenerated. Easily handled.	Drying unit is cyclic rather than continuous. May be plugged or disintegrated by contaminants. Relatively high heat requirements for regeneration	Dew-point depression of 100° F or more
Chemical methods: Phosphorus pentoxide, P_2O_5	Highest drying efficiency. Good capacity	Difficult to handle. Corrosive. Becomes wet and sticky when saturated. Strongly acid.	Not used on large-scale gas drying
Barium oxide, BaO. Precipitated by heating $BaCO_3$	Will dehydrate at temp up to 1000° F. Cheap. Granular. Easily handled. Efficiency practically equal to P_2O_5. Large capacity.	Expands on hydration. Cannot be regenerated. Strong alkali.	
Magnesium perchlorate (anhydrous; trihydrate)	Anhydrous form reported to have efficiency of P_2O_5. Large capacity. Contracts on adsorbing water. Chemically neutral.	Not suitable for flammable or acid gases (reacts to form explosive perchloric acid	
Magnesium oxide, MgO	High activity	Low capacity	Not used on large-scale gas drying
Unslaked lime, CaO	High capacity	Corrosive. Hard to handle	
Combination methods:			
Single-stage			
Combined absorption-adsorption (Hi-Florite, alumina, $CaCl_2$, impregnated Drierite, etc.)	Relatively high capacity. Good efficiency	Loss of impregnated salt at high moisture saturation. Higher initial cost of desiccant. Corrosive (depending on nature of impregnated salt)	
Combined use of refrigeration and liquid absorbent	Higher dew-point depression than absorbent alone. Less danger of freeze-ups than refrigeration alone	Must be preceded by gasoline plant on natural-gas systems to prevent formation of condensate. Relatively complex plant operation	
Multiple-stage compression followed by solid adsorption	Compression followed by cooling reduces moisture load and size of equipment for solid absorbent	Economical only where higher pressures are necessary for some other purpose	

*Amero, Moore, and Cappell, *Chem. Eng. Progress*, April, 1947. Reproduced by permission of the authors, the Floridin Company, Warren, Pa., and the AIChE.

By permission, from "Natural Gas and Natural Gasoline," by R. L. Huntington. Copyright 1950. McGraw-Hill Book Company.

DIETHYLENE GLYCOL PROCESS

It has been established that solids resembling ice or snow form under certain conditions in natural gas transmission lines operating at elevated pressures. The solids, called hydrates, are a combination of water and hydrocarbon components of the gas and restrict flow in the line and clog pressure regulators and valves. Formation of hydrates can be eliminated by dehydrating the gas entering the lines or by the use of anti-freeze agents such as methanol. Dehydration is the method commonly used today to prevent hydrate formation in long distance lines, although anti-freeze agents are occasionally used. Most pipe line companies now specify a maximum permissible water content of gas entering their transmission systems.

The glycols are noted for their hygroscopicity which is one of the characteristics that has led to their widespread industrial use. Diethylene glycol has been successfully used to dehydrate natural gas for 15 years. Triethylene glycol has been used to dehumidify air since 1939, although it has been used for natural gas dehydration only recently. Both of these high boiling point glycols are thermally stable and do not oxidize or decompose in normal plant use. Make-up requirements are, therefore, small. The dew point depression obtainable in a glycol dehydration plant depends upon the temperature at which contact occurs, as well as the concentration of glycol in the circulated solution. More natural gas is dehydrated today by means of the glycols than by any other method.

A glycol type dehydration plant contains a minimum of equipment and inexpensive "package" units are available from several manufacturers. Many such plants do not require constant supervision and are, therefore, inexpensive to operate. The introduction of plants of this type makes possible dehydration of gas at the well head, thus eliminating the need for line heaters in field gathering systems. The glycol process consists of scrubbing the gas stream to be dehydrated with a glycol-water mixture in a plate or packed column. The dehydrated gas leaves the top of the contactor after passing through a mist extractor section. The dilute glycol solution which has removed the majority of the water from the gas stream leaves the bottom of the contactor and passes through a heat exchanger into a concentrator in which water is removed. In most plants the concentrator consists of a still provided with heat exchange surface for further heating the glycol solution and a fractionating column to reduce the loss of glycol vapor in the overhead. Heating may be accomplished by direct firing, steam or hot oil. Other methods of concentrating the solution, such as a vacuum distillation, are used in special cases. After leaving the concentrator, the glycol is heat exchanged with the incoming dilute solution, may be further cooled with water if necessary, and returned to the top of the contactor to repeat the dehydration cycle.

Carbide and Chemicals Company.

COMPRESSING AIR AND GAS

In compressing a gas, if the heat of compression is removed so as to keep its temperature constant, it is called Isothermal Compression.

If all the heat of compression is retained in the gas and used to increase its temperature, it is called Adiabatic Compression.

In present-day reciprocating compressors, the air or gas is compressed very nearly adiabatically. The water-jacketing brings the compression curve somewhat below the adiabatic, but the excess pressure required to force the air or gas through the valves makes the work done very close to that which would be calculated on the assumption of adiabatic compression for the entire cylinder of air or gas.

The following formulae apply to adiabatic compression:

$$\text{m. e. p.} = \frac{n}{n-1} P_1 \left\{ \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right\}$$

$$\text{i. h. p.} = \frac{\text{m. e. p.} \times L A N}{33{,}000}$$

Where

m. e. p. = mean effective pressure in compressor cylinder.
i. h. p. = indicated horse power.
n = ratio of the specific heat a constant pressure to the specific heat at constant volume for air or the gas being compressed (see the table opposite).
P_1 = inlet pressure—pounds per square inch absolute.
P_2 = discharge pressure—pounds per square inch absolute.
$r = \frac{P_2}{P_1}$
L = length of stroke of compressor in feet.
A = effective area of cylinder in square inches.
N = number of strokes per minute.

For adiabatic compression of air in a single stage:

$$\left.\begin{matrix}\text{i. h. p. per 100 cu. ft.} \\ \text{piston displacement} \\ \text{per min.}\end{matrix}\right\} = 1.51\, P_1 (r^{0.29} - 1)$$

Since the values of n for the principal constituents of manufactured gas do not differ substantially from that for air this formula may be applied to manufactured gas.

For natural gas (when n = 1.275) the corresponding formula would be:

$$\left.\begin{matrix}\text{i. h. p. per 100 cu. ft.} \\ \text{piston displacement} \\ \text{per min.}\end{matrix}\right\} 2.023\, P_1 (r^{0.216} - 1)$$

Indicated horse power must be divided by overall efficiency to obtain brake or delivered horse power.

Values of n for certain gases are as follows:

Acetylene (C_2H_2)	1.26
Air	1.403
Ammonia (NH_3)	1.310
Butane (C_4H_{10})	1.108
Carbon Dioxide (CO_2)	1.304
Carbon Monoxide (CO)	1.404
Ethane (C_2H_6)	1.22
Ethylene (C_2H_4)	1.255
Hydrogen (H_2)	1.410
Methane (CH_4)	1.31
Nitrogen (N_2)	1.404
Oxygen (O_2)	1.401
Propane (C_3H_8)	1.15
Water Vapor (H_2O)	1.324

Theoretical Horse Power Required to Compress 100 cu. ft. of Air from Atmospheric Pressure (14.7 lbs.) to Various Gauge Pressures:

Adiabatic Compression

Discharge Pressure	H. P.		Discharge Pressure	H. P.	
Lbs. Gauge	Single Stage	Two Stage	Lbs. Gauge	Single Stage	Two Stage
5	1.9	..	80	15.9	13.7
10	3.6	..	90	16.9	14.5
15	5.0	..	100	18.0	15.4
20	6.2	..	120	19.9	16.8
25	7.4	..	140	21.6	18.0
30	8.4	..	160	..	19.1
35	9.4	..	180	..	20.1
40	10.3	..	200	..	21.0
45	11.1	..	250	..	23.0
50	11.9	..	300	..	24.7
55	12.6	..	400	..	27.6
60	13.3	..	500	..	29.8
65	14.0	..	600	..	31.7
70	14.6	12.8	..	..	..
75	15.3	13.3	..	..	..

Approximate Brake Horse Power Required by Air Compressors per 100 cu. ft. of free air actually delivered.

Altitude Feet	Single Stage Lbs. per sq. in. gauge			Two Stage Lbs. per sq. in. gauge			
	60	80	100	60	80	100	125
0	16.3	19.5	22.1	14.7	17.1	19.1	21.3
1000	16.1	19.2	21.7	14.5	16.8	18.7	20.9
2000	15.9	18.9	21.3	14.3	16.5	18.4	20.5
3000	15.7	18.6	20.9	14.0	16.1	18.0	20.0
4000	15.4	18.2	20.6	13.8	15.8	17.7	19.6
5000	15.2	17.9	20.3	13.5	15.5	17.3	19.2

Actual Delivery

The actual delivery of a single-stage compressor pumping to 100 lbs. gauge from atmosphere will be from 65 per cent to 80 per cent of its piston displacement, depending upon its clearance space and valve gear. A compound machine compressing to 100 lbs. gauge with an inter-cooler pressure of about 27 lbs. gauge will deliver from 80 per cent to 90 per cent of its piston displacement.

Displacement

A convenient formula for calculating the displacement of a double-acting cylinder is — square of the Diameter (inches) × stroke (inches) × R.P.M. × .0009 = piston displacement (c.f.m.). This makes a reasonable allowance for the piston rod on all piston sizes from about 5″ diam. to about 30″ diam.

Data on Compression from "Compressed Air Data," Ingersoll-Rand Co.

Two Stage Compression

Two stage compression is generally used where the compression ratio r is in excess of 5 or 6. An intercooler is used between the two stages.

To secure the desired pressure with minimum work, equal work should be done in the two stages and the intermediate temperature of the gas should be reduced to that at the inlet.

Then $P_{Intermediate}$ should be $\sqrt{P_1 \times P_2}$

Also the compression ratio in each stage should equal the square root of the over-all compression ratio.

For manufactured gas (2 stage compression):

Total i.h.p. per 100 cu. ft. piston displacement per min. $\Big\}$ $3.02P_1\,(r^{0.145}-1)$

For natural gas (2 stage compression with n = 1.275):

Total i.h.p. per 100 cu. ft. piston displacement per min. $\Big\}$ $4.046\,(r^{0.108}-1)$

Compression Temperatures

For adiabatic compression

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = r^{\frac{n-1}{n}}$$

Where

T_1 = absolute inlet temperature.
T_2 = absolute discharge temperature.
P_1, P_2 and r as indicated above.

For manufactured gas $\frac{T_2}{T_1} = r^{0.29}$

For natural gas $\frac{T_2}{T_1} = r^{0.216}$

For two stage compression with intercooling to inlet temperature of the gas $\frac{T_2}{T_1} = r^{\frac{n-1}{2n}}$

Multi-Stage Compression

In general, multi-stage compression with intercooling between stages;

(1) Reduces final gas temperature.
(2) Reduces horsepower to compress.
(3) Partially removes entrained moisture.
(4) Increases volumetric efficiency by reducing clearance expansion loss.
(5) Generally reduces maximum piston loads below those which would be found in a single-stage compressor of equal displacement.

Ingersoll-Rand Co.

BRAKE HORSE POWER FORMULA
for compressing natural gas

$$BHP = \frac{R}{R - JP}\left(\frac{5.16 \quad 124 \log. R}{0.97 - 0.03R}\right)$$

where

BHP = brake horse power required to compress one million cubic feet of natural gas per day
R = ratio of compression = $\frac{P_1}{P_2}$
P_1 = compressor discharge, psia
P_2 = compressor suction, psia
J = factor for supercompressibility (assumed .022 per 100 psia

BHP PER MILLION CU. FT. OF GAS COMPRESSED

Ratio of Compression	BHP Per Million C.F. Per Day Natural Gas	Manufactured Gas	Ratio of Compression	BHP Per Million C.F. Per Day Natural Gas	Manufactured Gas	Ratio of Compression	BHP Per Million C.F. Per Day Natural Gas	Manufactured Gas
1.2	15.5	15.5	2.8	63.0	65.0	4.4	93.5	98.0
1.3	20.5	20.5	2.9	65.5	67.5	4.5	95.5	100.0
1.4	25.0	25.0	3.0	67.5	70.0	4.6	97.0	101.5
1.5	28.5	29.0	3.1	69.5	72.0	4.7	99.0	103.5
1.6	32.0	32.5	3.2	71.5	74.0	4.8	101.0	106.0
1.7	35.5	36.5	3.3	73.5	76.5	4.9	102.5	107.5
1.8	38.5	39.5	3.4	75.5	78.0	5.0	104.0	109.5
1.9	41.5	42.0	3.5	77.5	80.5	5.1	106.0	111.5
2.0	44.0	45.0	3.6	79.0	82.5	5.2	107.5	113.0
2.1	46.5	47.5	3.7	81.0	84.5	5.3	109.0	115.0
2.2	49.0	50.5	3.8	83.0	86.5	5.4	110.5	116.5
2.3	51.5	53.0	3.9	84.5	88.5	5.5	112.5	118.5
2.4	54.0	55.5	4.0	86.5	90.5	5.6	114.0	120.0
2.5	56.5	58.0	4.1	88.5	92.5	5.7	115.5	122.0
2.6	58.5	60.5	4.2	90.5	94.0	5.8	117.0	124.0
2.7	61.0	63.0	4.3	92.0	96.0	5.9	118.5	125.5
						6.0	120.0	127.0

Clark Bros. Company

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It has been established that solids resembling ice or snow form under certain conditions in natural gas transmission lines operating at elevated pressures. The solids, called hydrates, are a combination of water and hydrocarbon components of the gas and restrict flow in the line and clog pressure regulators and valves. Formation of hydrates can be eliminated by dehydrating the gas entering the lines or by the use of anti-freeze agents such as methanol. Dehydration is the method commonly used today to prevent hydrate formation in long distance lines, although anti-freeze agents are occasionally used. Most pipe line companies now specify a maximum permissible water content of gas entering their transmission systems.

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In present-day reciprocating compressors, the air or gas is compressed very nearly adiabatically. The water-jacketing brings the compression curve somewhat below the adiabatic, but the excess pressure required to force the air or gas through the valves makes the work done very close to that which would be calculated on the assumption of adiabatic compression for the entire cylinder of air or gas.

The following formulae apply to adiabatic compression:

$$\text{m. e. p.} = \frac{n}{n-1} P_1 \left\{ \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right\}$$

$$\text{i. h. p.} = \frac{\text{m. e. p.} \times L A N}{33{,}000}$$

Where

m. e. p. = mean effective pressure in compressor cylinder.
i. h. p. = indicated horse power.
n = ratio of the specific heat a constant pressure to the specific heat at constant volume for air or the gas being compressed (see the table opposite).
P_1 = inlet pressure—pounds per square inch absolute.
P_2 = discharge pressure—pounds per square inch absolute.
$r = \frac{P_2}{P_1}$
L = length of stroke of compressor in feet.
A = effective area of cylinder in square inches.
N = number of strokes per minute.

For adiabatic compression of air in a single stage:

$$\left.\begin{matrix}\text{i. h. p. per 100 cu. ft.} \\ \text{piston displacement} \\ \text{per min.}\end{matrix}\right\} = 1.51\, P_1 (r^{0.29} - 1)$$

Since the values of n for the principal constituents of manufactured gas do not differ substantially from that for air this formula may be applied to manufactured gas.

For natural gas (when n = 1.275) the corresponding formula would be:

$$\left.\begin{matrix}\text{i. h. p. per 100 cu. ft.} \\ \text{piston displacement} \\ \text{per min.}\end{matrix}\right\} 2.023\, P_1 (r^{0.216} - 1)$$

Indicated horse power must be divided by overall efficiency to obtain brake or delivered horse power.

Values of n for certain gases are as follows:

Acetylene (C_2H_2)	1.26
Air	1.403
Ammonia (NH_3)	1.310
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Propane (C_3H_8)	1.15
Water Vapor (H_2O)	1.324

Theoretical Horse Power Required to Compress 100 cu. ft. of Air from Atmospheric Pressure (14.7 lbs.) to Various Gauge Pressures:

Adiabatic Compression

Discharge Pressure	H. P.		Discharge Pressure	H. P.	
Lbs. Gauge	Single Stage	Two Stage	Lbs. Gauge	Single Stage	Two Stage
5	1.9	..	80	15.9	13.7
10	3.6	..	90	16.9	14.5
15	5.0	..	100	18.0	15.4
20	6.2	..	120	19.9	16.8
25	7.4	..	140	21.6	18.0
30	8.4	..	160	..	19.1
35	9.4	..	180	..	20.1
40	10.3	..	200	..	21.0
45	11.1	..	250	..	23.0
50	11.9	..	300	..	24.7
55	12.6	..	400	..	27.6
60	13.3	..	500	..	29.8
65	14.0	..	600	..	31.7
70	14.6	12.8	..	..	..
75	15.3	13.3	..	..	..

Approximate Brake Horse Power Required by Air Compressors per 100 cu. ft. of free air actually delivered.

Altitude Feet	Single Stage Lbs. per sq. in. gauge			Two Stage Lbs. per sq. in. gauge			
	60	80	100	60	80	100	125
0	16.3	19.5	22.1	14.7	17.1	19.1	21.3
1000	16.1	19.2	21.7	14.5	16.8	18.7	20.9
2000	15.9	18.9	21.3	14.3	16.5	18.4	20.5
3000	15.7	18.6	20.9	14.0	16.1	18.0	20.0
4000	15.4	18.2	20.6	13.8	15.8	17.7	19.6
5000	15.2	17.9	20.3	13.5	15.5	17.3	19.2

Actual Delivery

The actual delivery of a single-stage compressor pumping to 100 lbs. gauge from atmosphere will be from 65 per cent to 80 per cent of its piston displacement, depending upon its clearance space and valve gear. A compound machine compressing to 100 lbs. gauge with an inter-cooler pressure of about 27 lbs. gauge will deliver from 80 per cent to 90 per cent of its piston displacement.

Displacement

A convenient formula for calculating the displacement of a double-acting cylinder is — square of the Diameter (inches) × stroke (inches) × R.P.M. × .0009 = piston displacement (c.f.m.). This makes a reasonable allowance for the piston rod on all piston sizes from about 5″ diam. to about 30″ diam.

Data on Compression from "Compressed Air Data," Ingersoll-Rand Co.

Two Stage Compression

Two stage compression is generally used where the compression ratio r is in excess of 5 or 6. An intercooler is used between the two stages.

To secure the desired pressure with minimum work, equal work should be done in the two stages and the intermediate temperature of the gas should be reduced to that at the inlet.

Then $P_{Intermediate}$ should be $\sqrt{P_1 \times P_2}$

Also the compression ratio in each stage should equal the square root of the over-all compression ratio.

For manufactured gas (2 stage compression):

Total i.h.p. per 100 cu. ft. piston displacement per min. $\} = 3.02P_1 (r^{0.148} - 1)$

For natural gas (2 stage compression with n = 1.275):

Total i.h.p. per 100 cu. ft. piston displacement per min. $\} = 4.046 (r^{0.108} - 1)$

Compression Temperatures

For adiabatic compression

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = r^{\frac{n-1}{n}}$$

Where

T_1 = absolute inlet temperature.
T_2 = absolute discharge temperature.
P_1, P_2 and r as indicated above.

For manufactured gas $\frac{T_2}{T_1} = r^{0.29}$

For natural gas $\frac{T_2}{T_1} = r^{0.216}$

For two stage compression with intercooling to inlet temperature of the gas $\frac{T_2}{T_1} = r^{\frac{n-1}{2n}}$

Multi-Stage Compression

In general, multi-stage compression with intercooling between stages;

(1) Reduces final gas temperature.
(2) Reduces horsepower to compress.
(3) Partially removes entrained moisture.
(4) Increases volumetric efficiency by reducing clearance expansion loss.
(5) Generally reduces maximum piston loads below those which would be found in a single-stage compressor of equal displacement.

Ingersoll-Rand Co.

BRAKE HORSE POWER FORMULA
for compressing natural gas

$$BHP = \frac{R}{R \quad JP} \qquad \frac{5.16 \quad 124 \log. R}{0.97 - 0.03R}$$

where

BHP = brake horse power required to compress one million cubic feet of natural gas per day

R = ratio of compression = $\frac{P_1}{P_2}$

P_1 = compressor discharge, psia

P_2 = compressor suction, psia

J = factor for supercompressibility (assumed .022 per 100 psia

BHP PER MILLION CU. FT. OF GAS COMPRESSED

Ratio of Compression	BHP Per Million C.F. Per Day Natural Gas	Manufactured Gas	Ratio of Compression	BHP Per Million C.F. Per Day Natural Gas	Manufactured Gas	Ratio of Compression	BHP Per Million C.F. Per Day Natural Gas	Manufactured Gas
1.2	15.5	15.5	2.8	63.0	65.0	4.4	93.5	98.0
1.3	20.5	20.5	2.9	65.5	67.5	4.5	95.5	100.0
1.4	25.0	25.0	3.0	67.5	70.0	4.6	97.0	101.5
1.5	28.5	29.0	3.1	69.5	72.0	4.7	99.0	103.5
1.6	32.0	32.5	3.2	71.5	74.0	4.8	101.0	106.0
1.7	35.5	36.5	3.3	73.5	76.5	4.9	102.5	107.5
1.8	38.5	39.5	3.4	75.5	78.0	5.0	104.0	109.5
1.9	41.5	42.0	3.5	77.5	80.5	5.1	106.0	111.5
2.0	44.0	45.0	3.6	79.0	82.5	5.2	107.5	113.0
2.1	46.5	47.5	3.7	81.0	84.5	5.3	109.0	115.0
2.2	49.0	50.5	3.8	83.0	86.5	5.4	110.5	116.5
2.3	51.5	53.0	3.9	84.5	88.5	5.5	112.5	118.5
2.4	54.0	55.5	4.0	86.5	90.5	5.6	114.0	120.0
2.5	56.5	58.0	4.1	88.5	92.5	5.7	115.5	122.0
2.6	58.5	60.5	4.2	90.5	94.0	5.8	117.0	124.0
2.7	61.0	63.0	4.3	92.0	96.0	5.9	118.5	125.5
						6.0	120.0	127.0

Clark Bros. Company

Theoretical Temperatures Reached in Compressing Gas from Atmospheric Pressure (14.7 lbs.) and 60° F. to Various Gauge Pressures.

Discharge Pressure	Discharge Temperatures Single Stage Mf'd Gas	Natural Gas
5	106°	94°
10	144°	121°
15	177°	145°
20	207°	166°
25	234°	184°
30	258°	201°
35	280°	216°
40	301°	230°
45	320°	243°
50	339°	256°
55	356°	267°
60	373°	279°
65	389°	289°
70	404°	299°
75	419°	308°
80	432°	317°
90	459°	334°
100	484°	351°
120	533°	379°
140	569°	405°

Discharge Pressure	Discharge Temperatures Two Stage Mf'd Gas	Natural Gas
45	177°	145°
50	185°	150°
55	191°	155°
60	198°	160°
65	204°	164°
70	210°	168°
75	216°	172°
80	221°	176°
90	231°	183°
100	240°	189°
120	257°	200°
140	272°	211°
160	285°	219°
180	296°	227°
200	307°	235°
250	331°	250°
300	351°	264°

Figures for manufactured gas are also applicable to air.

Actual discharge temperatures will be somewhat less than the above figures because of radiation and of heat carried off by the cooling water from the cylinder jackets.

Example 1. One million cubic feet of gas per day, saturated with water vapor and at a temperature of 75° F., is delivered to the low pressure distribution system. There it is cooled to 60° F. What is the amount of condensation per day in the mains?

Moisture per M @ 75° F. ..... 1.35 lbs.
Moisture per M @ 70° F., 50 lbs. .26 lbs.

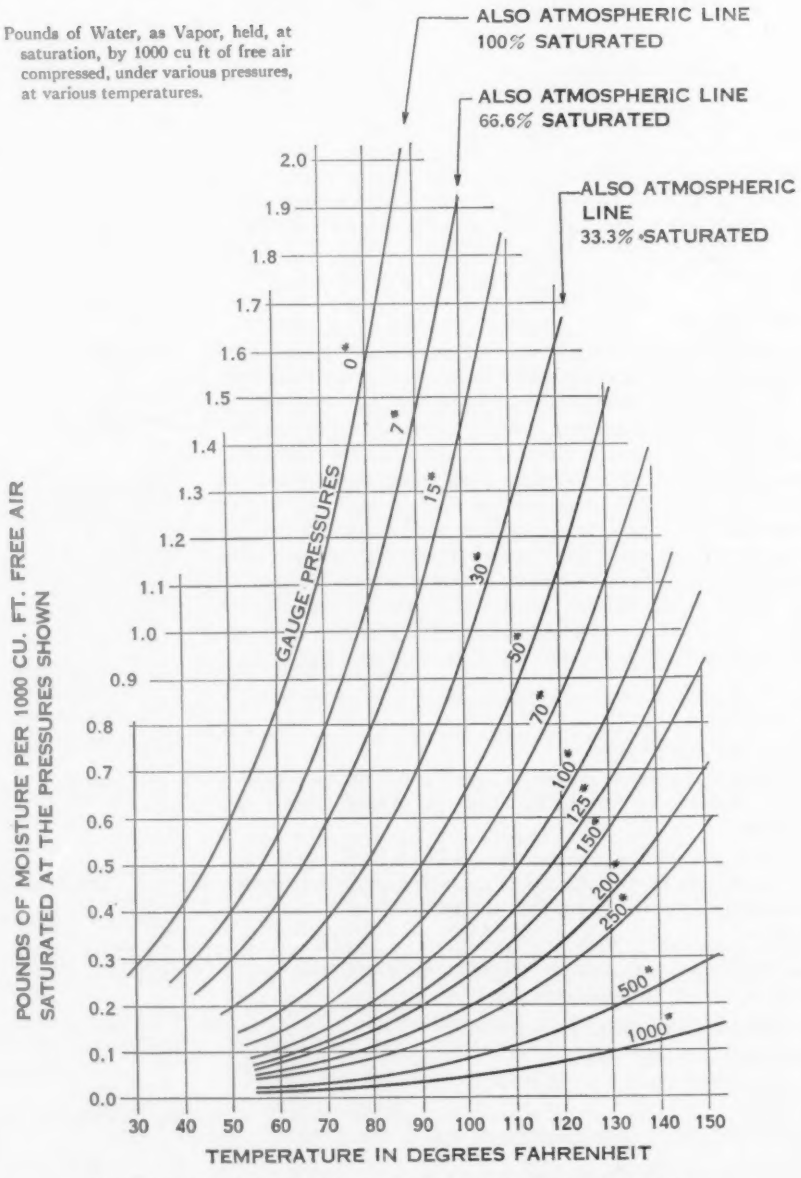
Condensation per M ..... .73 lbs.
1000 M × .73 = 730 lbs. condensation per day

Example 2. Same conditions as Example 1, except that gas is sent out on medium pressure system at 7 lbs. per sq. in. pressure.

Moisture per M @ 75° F., 0 lbs. 1.35 lbs.
Moisture per M @ 60° F., 7 lbs. .56 lbs.

Condensation per M ..... .79 lbs.
1000 M × .79 = 790 lbs. condensation per day

GAS AND AIR SATURATION CHART



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Example 3. One million cubic feet of gas per day, saturated with water vapor and at a temperature of 75° F., is compressed to 50 lbs. pressure, and then passes through an aftercooler where its temperature is reduced to 70° F. Thereafter it passes to the transmission system where its temperature is further reduced to 60° F. (a) How much moisture per day will be removed by a suitable separator at the outlet of the aftercooler? (b) How much moisture per day will be condensed in the transmission system at 50 lbs. and 60° F.? (c) To what pressure must the gas have fallen by the time its temperature dropped to 60° F. if there was no condensation in the transmission mains?

(a)

Moisture per M @ 75° F., 0 lbs. 1.35 lbs.
Moisture per M @ 70° F., 50 lbs. .25 lbs.

Condensation per M ..... 1.09 lbs.
1000 M × 1.09 = 1090 lbs. condensation per day at aftercooler outlet.

(b)

Moisture per H @ 70° F., lbs. .. .26 lbs.
Moisture per M @ 60° F., 50 lbs. .19 lbs.
Condensation per M ..... .07 lbs.

1000 M × .07 = 70 lbs. condensation per day in transmission mains.

(c)

Pressure at which .26 lbs. of moisture will saturate gas at a temperature of 60° F., is 32 lbs. (Read from chart.)

INSTRUCTIONS FOR COMPUTING FLOW OF GAS THROUGH ORIFICE METERS

Table and figure numbers given here (pages 51 to 62) are the same as given in "Gas Measurement Committee Report, No. 2, American Gas Association, from which these data were taken.
—Editor.

General Equation

In the measurement of most gases, and especially natural gas, it is almost the universal practice (in the United States) to express the flow in cubic feet per hour referred to some specified reference or base condition of pressure and temperature. For the calculation of the quantity of gas the committee* recommends the continued use of the formula:

$$Q_h = C' \sqrt{h_w p_f} \qquad (1)$$

in which

Q_h = Quantity rate of flow at base conditions, ft³/hr.
C' = Orifice flow constant.
h_w = Differential pressure in inches of water.
p_f = Absolute static pressure in Lbs./sq. in.

Orifice Flow Constant

The orifice flow constant, C′, may be defined as the rate of flow, in cu. ft. per hour, at base conditions, when the extension, $\sqrt{h_w p_f}$ equals one. It was formerly known as the "flow coefficient." It is here called "orifice flow constant." It is to be calculated by the following equation:

$$C' = F_b \times F_r \times Y \times F_{pb} \times F_{tb} \times F_{tf} \times F_g \times F_{pv} \qquad (2)$$

in which

F_b = Basic orifice flow factor
F_r = Reynolds' number factor
Y = Expansion factor
F_{pb} = Pressure base factor
F_{tb} = Temperature base factor
F_{tf} = Flowing temperature factor
F_g = Specific gravity factor
F_{pv} = Supercompressibility factor

It will be noted that all of the factors used in calculating the orifice flow constants are familiar except F_r, F_b, Y and F_{pv}.

The values of all the factors F_b, F_r, etc., are obtained from the tables. The following method is for a meter with flange taps. The method for a meter with pipe taps will be exactly the same, except that the tables for pipe taps will be used.

Basic Orifice Flow Factor

The basic orifice flow factor, F_b, is taken directly from Table 4, for the correct orifice and pipe size. For sizes not listed in this table, the value of F_b may be found by calculation as explained in Appendix B of this report. (Interpolation should not be relied upon). The pipe diameter of the orifice sections, it is important to point out, should be within the limits specified in Table 2. If the value of D_1 is outside of those limits the flow factors of Table 4 cannot be relied upon. Then the exact value of F_b should be calculated, for the particular value of "β" based on the actual value of D_1.

Reynolds' Number Factor

The Reynolds' number factor, F_r, is taken from Table 6. For its determination the average extension at which the meter operates must be known in addition to the orifice and pipe size.

The value of $\sqrt{h_w p_f}$ (extension) used in selecting the F_r factor from Table 6 may be based upon the meter record, or estimated from a knowledge of the average static pressure and the average differential at which the meter may operate. This extension, it should be noted, is an index with which a factor is selected, and does not enter directly into the computations. An extension value selected as suggested will probably be sufficiently close to the average operating conditions of the meter for selecting the proper value of F_r, especially since the variations in F_r corresponding to values of $\sqrt{h_w p_f}$ above or below the selected average will be compensating (plus or minus) over any appreciable length of time.

* From the Gas Measurement Committee Report, American Gas Association.

Orifice to Pipe Diameter	Recommended Maximum Allowable Tolerance between Measured inside Diameter of the upstream section of the meter run, and the Published "Approximate Internal Diameter", which was used in Computing Basic Orifice Constants of this Report.	
Ratio "β"	Flange Taps	Pipe Taps
.10 to .25	5.0%	3.5%
.25 to .35	3.0%	2.0%
.35 to .45	2.0%	1.0%
.45 to .55	1.5%	0.6%
.55 to .65	1.0%	0.3%
.65 to .75	0.5%	0.2%

TABLE 2

The tables, it should be noted, have been calculated by using average values of viscosity, 0.0000069 Lb./ft.-sec., of temperature, 520° F. absolute, and of gravity, 0.65, applying particularly to natural gas. If the gas being metered has a viscosity, temperature or gravity quite different from these, the value of F_r in Table 6 may not be applicable. However, for variations in viscosity from .0000059 to .0000079, in temperatures of from 490° to 550° F. absolute, or in specific gravity of from .55 to .75, the variations in the factor F_r would be well within the tolerances given for this report.

Expansion Factor

The expansion factor, Y, is to be taken from Tables 8, 9, or 10, depending upon the tap location from which the static pressure is taken. Here the ratio h_w/p_f is an index with which the value of Y is selected, and may be based upon the meter record, or estimated from the average static pressure and the average differential at which the meter may operate. The effects of operating variations from this "average" h_w/p_f will ordinarily be compensating.

For meters with flange connections, the variations to be expected in meter accuracy from the average will be greater or less depending on whether upstream, downstream or intermediate pressure connections are used. As the h/p ratio is increased, it will be observed, the use of the intermediate static pressure gives the minimum departure from the mean condition used in the selection of the expansion factor.

With orifice meters using "pipe taps" the variation from the mean estimated operating value of h/p used in the determination of the expansion factor (Y) result in the greatest variation in the value of Y when upstream static pressures are used. The use of intermediate static pressures in connection with pipe taps has little advantage, since it only slightly reduces the variations in Y resulting from departures from the mean. The use of downstream static pressures for this type of connection results in the least change in the values of Y due to changes in the values of the h/p ratio from the mean operating value.

Note—In use it may be found that a group of meters in the same locality, or operating under the same conditions, will have the same values for F_r, and Y. If this is true the flow constants in this group will be the same for all plates of the same size and ratio.

Pressure Base Factor

The pressure base factor, F_{pb}, is taken from Table 13.

Temperature Base Factor

The temperature base factor, F_{tb}, is taken from Table 14.

Flowing Temperature Factor

The flowing temperature factor, F_{tf}, is taken from Table 15, and should be based on the actual flowing temperature of the gas.

Specific Gravity Factor

The specific gravity factor, F_g, is taken from Table 16, and should be based on the actual specific gravity of the gas as determined by test, and the portion of table nearest to this used, with linear interpolation if necessary.

Supercompressibility Factor

The supercompressibility factor, F_{pv}, is taken from Table 17, and should be based on the actual supercompressibility ratio, N, as determined by test.

The development of the general hydraulic flow equation involves the actual density of the fluid at the point of measurement. In the measurement of gas this depends upon the flowing pressure and temperature. To translate the calculated volume at the flowing pressure and temperature to base pressure and temperature, it is necessary to apply the law for an ideal gas. All gases deviate from this ideal gas law to a greater or lesser extent. This deviation has been termed "Supercompressibility." A factor to take account of this supercompressibility is necessary in the measurement of some gases. This factor is particularly appreciable at high line pressures. However, before any supercompressibility factor can be applied to the measurement of a particular gas, an actual determination of the deviation from the ideal gas law, over the range of flowing pressures and temperatures involved, must have been made.

Application and Examples

In the application of these factors, it will be noted that F_r, Y, F_{pb}, F_{tf}, F_g and F_{pv} are multipliers, and may be applied either to the basic orifice flow factor, F_b, or to the calculated quantity rate of flow, as preferred.

Examples of the calculation of the quantity rate of flow for various conditions, using the tables in this report follows:

Example 1.

Given:

D_1 = Line size = 8" Nominal inside diameter = 8.071" actual inside diameter.

D_2 = Orifice size = 1.000".

Meter equipped with Flange Taps, with static pressure from downstream tap.

T_f = Flowing temperature = 65° F.

P_b = 4 oz. above 14.4 Lb/sq. in. = 14.65 Lb/sq. in. absolute = pressure base.

T_b = Temperature base = 50° F. = 510° absolute.

Specific gravity = .570.

Average differential head h_w = 50" Water.

Average downstream static pressure, p_f = 40 Lb/sq. in. absolute.

Supercompressibility ratio (by Test), N = 0.004.

Required:

The orifice flow constant and the quantity rate of flow for one hour at base conditions.

$$\beta = \frac{D_2}{D_1} = .1239$$

Published approximate inside diameter of pipe = 8.071

Ratio actual inside diameter to approximate inside diameter = 1.000.

Per cent difference = 0.0 therefore Tables can be used.

Average $\sqrt{h_w p_f} = 44.72$

Average $\frac{h_w}{p_f} = 1.25$

From Table 4 for 1" plate in 8" line.

$F_b = 204.97$

From Table 6, 8" Line 1" Plate

for $\sqrt{h_w p_f} = 40$ $\quad F_r = 1.0017$

$\sqrt{h_w p_f} = 50$ $\quad F_r = 1.0014$

then at $\sqrt{h_w p_f} = 44.72$ $\quad F_r = 1.0015$

From Table 9 (Y_2 for downstream static pressure)

at $\frac{h_w}{p_f} = 1.2$ and $\beta = .1$ and .2; $\quad Y_2 = 1.0080$

at $\frac{h_w}{p_f} = 1.3$ and $\beta = .1$ and .2; $\quad Y_2 = 1.0087$

Interpolating for

$\frac{h_w}{p_f} = 1.25$ and $\beta = .1239$; $\quad Y_2 = 1.0084$

From Table 13

for 4 oz. above 14.4 Lb/sq. in.; $\quad F_{pb} = .9829$

From Table 14

for $T_b = 50°$ F.; $\quad F_{tb} = .9808$

From Table 15

for $T_f = 65°$ F.; $\quad F_{tf} = .9952$

From Table 16

for Specific Gravity = .570; $\quad F_g = 1.3245$

From Table 17

for N = .004 $\quad F_{pv} = 1.002$

Then the orifice flow constant is:

$C' = 204.97 \times 1.0015 \times 1.0088 \times .9829 \times .9808 \times .9952 \times 1.3245 \times 1.0020 = 263.65 =$ Orifice Flow Constant

and the rate of flow for 1 hour at base conditions is:

$Q_h = 263.65 \sqrt{50 \times 40} = 11791$

The same value of Q_h is obtained if the computations are made in this order:

$Q_h = [204.97 \times \sqrt{50 \times 40}] \times (1.0015 \times 1.0088 \times 0.9829 \times 0.9808 \times 0.9952 \times 1.3245 \times 1.0020) = 9166.5 \times 1.2863 = 11791$

ORIFICE METER TABLES FOR NATURAL GAS

The tolerances necessary in the use of any orifice meter do not warrant taking the values in these tables to be accurate beyond one in 500. Four figures are given in all cases solely to enable different computers to agree within 1 or 2 in the fourth significant figure regardless of whether it is on the right or left of the decimal.

In some of the tables values of the constants for a few of the smaller orifices are marked with an asterisk, these orifices have diameter ratios lower than the minimum value for which the formulas used were derived and this size of plate should not be used unless it is understood that the accuracy of measurement will be relatively low.

In preparing these tables the intermediate steps were usually carried out to 5 or 6 figures and the final value rounded off to the nearest fourth or fifth figure. When the fifth or sixth figure was a "5" the fourth or fifth figure was taken as the nearest *even* number.

TABLE 4 F_b BASIC ORIFICE FACTORS — FLANGE TAPS

Base Temperature = 60° F. Flowing Temperature = 60° F; $\sqrt{h_w p_f} = \infty$
Base Pressure = 14.4 Lb./Sq. in. abs; Specific Gravity = 1.0; $h_w/p_f = 0$

Pipe Sizes — Nominal and Actual Diameters

Orifice Diameter Inches	2" Std. 2.067	3" Std. 3.068	4" Std. 4.026	6" Std. 6.065	8" Std. 8.071	10" Std. 10.136	12" Std. 12.090	15¼" Std. 15.25
.250	13.002	12.996*	12.974*					
.375	29.079	29.026	28.989*					
.500	51.680	51.444	51.376	51.328*				
.625	81.129	80.426	80.218	80.080				
.750	117.77	116.16	115.67	115.30				
.875	162.11	158.70	157.81	157.08	156.82			
1.000	215.04	208.21	206.62	205.45	204.97			
1.125	277.93	264.97	262.21	260.39	259.69	259.27		
1.250	353.04	329.41	324.72	321.93	320.94	320.35	320.00	
1.375	443.44	402.10	394.35	390.11	388.73	387.95	387.47	
1.500	554.71	483.80	471.35	464.98	463.10	462.07	461.44	
1.625		575.47	556.06	546.62	544.07	542.73	541.93	541.06
1.750		678.61	648.93	635.11	631.64	629.94	628.93	627.85
1.875		794.99	750.50	730.55	725.90	723.73	722.48	721.15
2.000		926.76	861.42	833.06	826.86	824.11	822.56	820.95
2.125		1076.6	982.50	942.83	934.59	931.10	929.21	927.26
2.250		1251.2	1114.9	1060.0	1049.1	1044.7	1042.4	1040.1
2.375			1259.9	1184.9	1170.5	1165.1	1162.3	1159.5
2.500			1419.0	1317.7	1299.0	1292.1	1288.7	1285.4
2.625			1593.9	1458.7	1434.4	1425.8	1421.7	1417.9
2.750			1786.7	1608.3	1577.1	1566.4	1561.5	1557.0
2.875			2000.3	1767.0	1727.1	1713.8	1707.9	1702.6
3.000			2245.3	1935.2	1884.6	1868.2	1861.0	1854.9
3.125				2113.4	2049.7	2029.5	2020.9	2013.7
3.250				2302.4	2222.7	2197.8	2187.6	2179.2
3.375				2502.8	2403.7	2373.4	2361.1	2351.3
3.500				2715.7	2593.1	2556.1	2541.5	2530.1
3.625				2941.9	2791.1	2746.2	2728.9	2715.6
3.750				3182.5	2998.0	2943.8	2923.2	2907.9
3.875				3438.5	3214.2	3149.1	3124.6	3106.8
4.000				3711.4	3439.9	3362.1	3333.1	3312.5
4.250				4313.2	3922.0	3812.1	3772.0	3744.4
4.500				5013.1	4448.7	4295.5	4240.5	4203.8
4.750					5024.8	4812.8	4739.6	4691.2
5.000					5656.2	5369.9	5270.4	5206.7
5.250					6349.6	5965.5	5834.0	5751.2
5.500					7112.9	6604.3	6432.1	6324.8
5.750					7956.0	7289.8	7066.1	6928.6
6.000					8906.5	8026.3	7738.1	7563.0
6.250						8818.7	8450.0	8229.2
6.500						9672.0	9204.9	8927.9
6.750						10592	10006	9660.4
7.000						11587	10856	10428
7.250						12664	11759	11231
7.500						13851	12719	12073
7.750							13741	12954
8.000							14830	13877
8.250							15991	14843
8.500							17231	15856
8.750							18564	16918
9.000							20014	18031
9.250								19198
9.500								20426
9.750								21715
10.000								23070
10.250								24496
10.500								25997
10.750								27578
11.000								29253
11.250								31042

TABLE 6
F_r

REYNOLDS' NUMBER FACTORS — FLANGE TAPS

For 2″ Line

Orifice Diam. Inches	$\sqrt{h_w p_f}$																		
	4.0	4.5	5.0	5.5	6.0	7.0	8.0	10	12	15	20	25	30	35	40	50	70	100	200
.250	1.0232	1.0206	1.0185	1.0168	1.0154	1.0132	1.0116	1.0093	1.0077	1.0062	1.0046	1.0037	1.0031	1.0026	1.0023	1.0019	1.0013	1.0009	1.0005
.375	1.0181	1.0161	1.0145	1.0132	1.0121	1.0104	1.0091	1.0073	1.0060	1.0048	1.0036	1.0029	1.0024	1.0021	1.0018	1.0015	1.0010	1.0007	1.0004
.500	1.0147	1.0131	1.0118	1.0107	1.0098	1.0084	1.0073	1.0059	1.0049	1.0039	1.0029	1.0024	1.0020	1.0017	1.0015	1.0012	1.0008	1.0006	1.0003
.625	1.0126	1.0112	1.0101	1.0092	1.0084	1.0072	1.0063	1.0051	1.0042	1.0034	1.0025	1.0020	1.0017	1.0014	1.0013	1.0010	1.0007	1.0005	1.0003
.750	1.0118	1.0105	1.0094	1.0086	1.0079	1.0067	1.0059	1.0047	1.0039	1.0031	1.0024	1.0019	1.0016	1.0013	1.0012	1.0009	1.0007	1.0005	1.0002
.875	1.0119	1.0106	1.0095	1.0087	1.0080	1.0068	1.0060	1.0048	1.0040	1.0032	1.0024	1.0019	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0002
1.000	1.0129	1.0114	1.0103	1.0094	1.0086	1.0074	1.0064	1.0052	1.0043	1.0034	1.0026	1.0021	1.0017	1.0015	1.0013	1.0010	1.0007	1.0005	1.0003
1.125	1.0144	1.0128	1.0115	1.0104	1.0096	1.0082	1.0072	1.0057	1.0048	1.0038	1.0029	1.0023	1.0019	1.0016	1.0014	1.0011	1.0008	1.0006	1.0003
1.250	1.0161	1.0143	1.0129	1.0117	1.0108	1.0092	1.0081	1.0065	1.0054	1.0043	1.0032	1.0026	1.0022	1.0018	1.0016	1.0013	1.0009	1.0006	1.0003
1.375	1.0179	1.0159	1.0143	1.0130	1.0119	1.0102	1.0089	1.0072	1.0060	1.0048	1.0036	1.0029	1.0024	1.0020	1.0018	1.0014	1.0010	1.0007	1.0004
1.500	1.0193	1.0172	1.0155	1.0141	1.0129	1.0110	1.0097	1.0077	1.0064	1.0052	1.0039	1.0031	1.0026	1.0022	1.0019	1.0015	1.0011	1.0008	1.0004

For 4″ Line

Orifice Diam. Inches	$\sqrt{h_w p_f}$																		
	4.0	4.5	5.0	5.5	6.0	7.0	8.0	10	12	15	20	25	30	35	40	50	70	100	200
.250	1.0264	1.0234	1.0211	1.0192	1.0176	1.0151	1.0132	1.0105	1.0088	1.0070	1.0053	1.0042	1.0035	1.0030	1.0026	1.0021	1.0015	1.0011	1.0005
.375	1.0227	1.0202	1.0181	1.0165	1.0151	1.0130	1.0113	1.0091	1.0076	1.0060	1.0045	1.0036	1.0030	1.0026	1.0023	1.0018	1.0013	1.0009	1.0005
.500	1.0195	1.0173	1.0156	1.0142	1.0130	1.0111	1.0097	1.0078	1.0065	1.0052	1.0039	1.0031	1.0026	1.0022	1.0019	1.0016	1.0011	1.0008	1.0004
.625	1.0167	1.0149	1.0134	1.0122	1.0112	1.0096	1.0084	1.0067	1.0056	1.0045	1.0033	1.0027	1.0022	1.0019	1.0017	1.0013	1.0010	1.0007	1.0003
.750	1.0144	1.0128	1.0116	1.0105	1.0096	1.0083	1.0072	1.0058	1.0048	1.0039	1.0029	1.0023	1.0019	1.0017	1.0014	1.0012	1.0008	1.0006	1.0003
.875	1.0126	1.0112	1.0100	1.0091	1.0084	1.0072	1.0063	1.0050	1.0042	1.0033	1.0025	1.0020	1.0017	1.0014	1.0013	1.0010	1.0007	1.0005	1.0003
1.000	1.0110	1.0098	1.0088	1.0080	1.0074	1.0063	1.0055	1.0044	1.0037	1.0029	1.0022	1.0018	1.0015	1.0013	1.0011	1.0009	1.0006	1.0004	1.0002
1.125	1.0099	1.0088	1.0079	1.0072	1.0066	1.0057	1.0050	1.0040	1.0033	1.0026	1.0020	1.0016	1.0013	1.0011	1.0010	1.0008	1.0006	1.0004	1.0002
1.250	1.0091	1.0081	1.0073	1.0066	1.0061	1.0052	1.0046	1.0036	1.0030	1.0024	1.0018	1.0015	1.0012	1.0010	1.0009	1.0007	1.0005	1.0004	1.0002
1.375	1.0086	1.0077	1.0069	1.0063	1.0057	1.0049	1.0043	1.0034	1.0029	1.0023	1.0017	1.0014	1.0011	1.0010	1.0009	1.0007	1.0005	1.0003	1.0002
1.500	1.0084	1.0075	1.0067	1.0061	1.0056	1.0048	1.0042	1.0034	1.0028	1.0022	1.0017	1.0013	1.0011	1.0010	1.0008	1.0007	1.0005	1.0003	1.0002
1.625	1.0085	1.0075	1.0068	1.0062	1.0056	1.0048	1.0042	1.0034	1.0028	1.0023	1.0017	1.0014	1.0011	1.0010	1.0008	1.0007	1.0005	1.0003	1.0002
1.750	1.0088	1.0078	1.0070	1.0064	1.0058	1.0050	1.0044	1.0035	1.0029	1.0023	1.0018	1.0014	1.0012	1.0010	1.0009	1.0007	1.0005	1.0004	1.0002
1.875	1.0092	1.0082	1.0074	1.0067	1.0062	1.0053	1.0046	1.0037	1.0031	1.0025	1.0018	1.0015	1.0012	1.0011	1.0009	1.0007	1.0005	1.0004	1.0002
2.000	1.0099	1.0088	1.0079	1.0072	1.0066	1.0057	1.0049	1.0040	1.0033	1.0026	1.0020	1.0016	1.0013	1.0011	1.0010	1.0008	1.0006	1.0004	1.0002
2.125	1.0107	1.0095	1.0085	1.0078	1.0071	1.0061	1.0053	1.0043	1.0036	1.0028	1.0021	1.0017	1.0014	1.0012	1.0011	1.0009	1.0006	1.0004	1.0002
2.250	1.0116	1.0103	1.0093	1.0084	1.0077	1.0066	1.0058	1.0046	1.0039	1.0031	1.0023	1.0019	1.0015	1.0013	1.0012	1.0009	1.0007	1.0005	1.0002
2.375	1.0125	1.0111	1.0100	1.0091	1.0084	1.0072	1.0063	1.0050	1.0042	1.0033	1.0025	1.0020	1.0017	1.0014	1.0013	1.0010	1.0007	1.0005	1.0003
2.500	1.0135	1.0120	1.0108	1.0098	1.0090	1.0077	1.0068	1.0054	1.0045	1.0036	1.0027	1.0022	1.0018	1.0015	1.0014	1.0011	1.0008	1.0005	1.0003
2.625	1.0145	1.0129	1.0116	1.0105	1.0096	1.0083	1.0072	1.0058	1.0048	1.0039	1.0029	1.0023	1.0019	1.0017	1.0014	1.0012	1.0008	1.0006	1.0003
2.750	1.0154	1.0137	1.0123	1.0112	1.0103	1.0088	1.0077	1.0062	1.0051	1.0041	1.0031	1.0025	1.0021	1.0018	1.0015	1.0012	1.0009	1.0006	1.0003
2.875	1.0162	1.0144	1.0130	1.0118	1.0108	1.0093	1.0081	1.0065	1.0054	1.0043	1.0032	1.0026	1.0022	1.0019	1.0016	1.0013	1.0009	1.0006	1.0003
3.000	1.0168	1.0150	1.0135	1.0123	1.0112	1.0096	1.0084	1.0067	1.0056	1.0045	1.0034	1.0027	1.0022	1.0019	1.0017	1.0013	1.0010	1.0007	1.0003

For 6″ Line

Orifice Diam. Inches	$\sqrt{h_w p_f}$																		
	4.0	4.5	5.0	5.5	6.0	7.0	8.0	10	12	15	20	25	30	35	40	50	70	100	200
.500	1.0223	1.0198	1.0178	1.0162	1.0149	1.0127	1.0112	1.0089	1.0074	1.0059	1.0045	1.0036	1.0030	1.0025	1.0022	1.0018	1.0013	1.0009	1.0004
.625	1.0200	1.0178	1.0160	1.0146	1.0134	1.0114	1.0100	1.0080	1.0067	1.0053	1.0040	1.0032	1.0027	1.0023	1.0020	1.0016	1.0011	1.0008	1.0004
.750	1.0178	1.0158	1.0142	1.0129	1.0118	1.0101	1.0089	1.0071	1.0059	1.0047	1.0036	1.0028	1.0024	1.0020	1.0018	1.0014	1.0010	1.0007	1.0004
.875	1.0161	1.0143	1.0129	1.0117	1.0107	1.0092	1.0080	1.0064	1.0054	1.0043	1.0032	1.0026	1.0021	1.0018	1.0016	1.0013	1.0009	1.0006	1.0003
1.000	1.0144	1.0128	1.0115	1.0105	1.0096	1.0082	1.0072	1.0058	1.0048	1.0038	1.0029	1.0023	1.0019	1.0016	1.0014	1.0012	1.0008	1.0006	1.0003
1.125	1.0129	1.0115	1.0103	1.0094	1.0086	1.0074	1.0065	1.0052	1.0043	1.0034	1.0026	1.0021	1.0017	1.0015	1.0013	1.0010	1.0007	1.0005	1.0003
1.250	1.0116	1.0103	1.0093	1.0084	1.0077	1.0066	1.0058	1.0046	1.0039	1.0031	1.0023	1.0019	1.0015	1.0013	1.0012	1.0009	1.0007	1.0005	1.0002
1.375	1.0105	1.0093	1.0084	1.0076	1.0070	1.0060	1.0052	1.0042	1.0035	1.0028	1.0021	1.0017	1.0014	1.0012	1.0010	1.0008	1.0006	1.0004	1.0002
1.500	1.0095	1.0085	1.0076	1.0069	1.0063	1.0054	1.0048	1.0038	1.0032	1.0025	1.0019	1.0015	1.0013	1.0011	1.0010	1.0008	1.0005	1.0004	1.0002
1.625	1.0087	1.0077	1.0070	1.0063	1.0058	1.0050	1.0044	1.0035	1.0029	1.0023	1.0017	1.0014	1.0012	1.0010	1.0009	1.0007	1.0005	1.0003	1.0002
1.750	1.0081	1.0072	1.0065	1.0059	1.0054	1.0046	1.0040	1.0032	1.0027	1.0022	1.0016	1.0013	1.0011	1.0009	1.0008	1.0006	1.0005	1.0003	1.0002
1.875	1.0076	1.0067	1.0060	1.0055	1.0050	1.0043	1.0038	1.0030	1.0025	1.0020	1.0015	1.0012	1.0010	1.0009	1.0008	1.0006	1.0004	1.0003	1.0002
2.000	1.0072	1.0064	1.0058	1.0052	1.0048	1.0041	1.0036	1.0029	1.0024	1.0019	1.0014	1.0012	1.0010	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
2.125	1.0070	1.0062	1.0056	1.0051	1.0046	1.0040	1.0035	1.0028	1.0023	1.0019	1.0014	1.0011	1.0009	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
2.250	1.0068	1.0061	1.0055	1.0050	1.0046	1.0039	1.0034	1.0027	1.0023	1.0018	1.0014	1.0011	1.0009	1.0008	1.0007	1.0005	1.0004	1.0003	1.0001
2.375	1.0069	1.0061	1.0055	1.0050	1.0046	1.0039	1.0034	1.0027	1.0023	1.0018	1.0014	1.0011	1.0009	1.0008	1.0007	1.0005	1.0004	1.0003	1.0001
2.500	1.0070	1.0062	1.0056	1.0051	1.0046	1.0040	1.0035	1.0028	1.0023	1.0019	1.0014	1.0011	1.0009	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
2.625	1.0072	1.0064	1.0057	1.0052	1.0048	1.0041	1.0036	1.0029	1.0024	1.0019	1.0014	1.0011	1.0010	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
2.750	1.0075	1.0066	1.0060	1.0054	1.0050	1.0043	1.0037	1.0030	1.0025	1.0020	1.0015	1.0012	1.0010	1.0009	1.0007	1.0006	1.0004	1.0003	1.0001
2.875	1.0079	1.0070	1.0063	1.0057	1.0052	1.0045	1.0039	1.0031	1.0026	1.0021	1.0016	1.0013	1.0010	1.0009	1.0008	1.0006	1.0004	1.0003	1.0002
3.000	1.0083	1.0074	1.0066	1.0060	1.0055	1.0047	1.0042	1.0033	1.0028	1.0022	1.0017	1.0013	1.0011	1.0009	1.0008	1.0007	1.0005	1.0003	1.0002
3.125	1.0088	1.0078	1.0071	1.0064	1.0059	1.0050	1.0044	1.0035	1.0029	1.0024	1.0018	1.0014	1.0012	1.0010	1.0009	1.0007	1.0005	1.0004	1.0002
3.250	1.0094	1.0084	1.0075	1.0068	1.0063	1.0054	1.0047	1.0038	1.0031	1.0025	1.0019	1.0015	1.0013	1.0011	1.0009	1.0008	1.0005	1.0004	1.0002
3.375	1.0100	1.0089	1.0080	1.0073	1.0067	1.0057	1.0050	1.0040	1.0033	1.0027	1.0020	1.0016	1.0013	1.0011	1.0010	1.0008	1.0006	1.0004	1.0002
3.500	1.0106	1.0095	1.0085	1.0077	1.0071	1.0061	1.0053	1.0043	1.0035	1.0028	1.0021	1.0017	1.0014	1.0012	1.0011	1.0009	1.0006	1.0004	1.0002
3.625	1.0113	1.0100	1.0090	1.0082	1.0075	1.0065	1.0056	1.0045	1.0038	1.0030	1.0023	1.0018	1.0015	1.0013	1.0011	1.0009	1.0006	1.0005	1.0002
3.750	1.0120	1.0106	1.0096	1.0087	1.0080	1.0068	1.0060	1.0048	1.0040	1.0032	1.0024	1.0019	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0002
3.875	1.0126	1.0112	1.0101	1.0092	1.0084	1.0072	1.0063	1.0050	1.0042	1.0034	1.0025	1.0020	1.0017	1.0014	1.0013	1.0010	1.0007	1.0005	1.0003
4.000	1.0133	1.0118	1.0106	1.0097	1.0089	1.0076	1.0066	1.0053	1.0044	1.0035	1.0027	1.0021	1.0018	1.0015	1.0013	1.0011	1.0008	1.0005	1.0003
4.250	1.0145	1.0129	1.0116	1.0105	1.0097	1.0083	1.0072	1.0058	1.0048	1.0039	1.0029	1.0023	1.0019	1.0017	1.0014	1.0012	1.0008	1.0006	1.0003
4.500	1.0155	1.0138	1.0124	1.0113	1.0103	1.0088	1.0077	1.0062	1.0052	1.0041	1.0031	1.0025	1.0021	1.0018	1.0015	1.0012	1.0009	1.0006	1.0003

TABLE 6 — Continued

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REYNOLDS' NUMBER FACTORS — FLANGE TAPS

For 8″ Line

Orifice Diam. Inches	$\sqrt{h_w p_f}$																		
	4.0	4.5	5.0	5.5	6.0	7.0	8.0	10	12	15	20	25	30	35	40	50	70	100	200
.875	1.0185	1.0165	1.0148	1.0135	1.0124	1.0106	1.0093	1.0074	1.0062	1.0049	1.0037	1.0030	1.0025	1.0021	1.0019	1.0015	1.0011	1.0007	1.0004
1.000	1.0170	1.0151	1.0136	1.0124	1.0113	1.0097	1.0085	1.0068	1.0057	1.0045	1.0034	1.0027	1.0023	1.0019	1.0017	1.0014	1.0010	1.0007	1.0003
1.125	1.0156	1.0138	1.0125	1.0113	1.0104	1.0089	1.0078	1.0062	1.0052	1.0042	1.0031	1.0025	1.0021	1.0018	1.0016	1.0012	1.0009	1.0006	1.0003
1.250	1.0143	1.0127	1.0114	1.0104	1.0095	1.0082	1.0071	1.0057	1.0048	1.0038	1.0029	1.0023	1.0019	1.0016	1.0014	1.0011	1.0008	1.0006	1.0003
1.375	1.0131	1.0116	1.0105	1.0095	1.0087	1.0075	1.0065	1.0052	1.0044	1.0035	1.0026	1.0021	1.0017	1.0015	1.0013	1.0010	1.0007	1.0005	1.0003
1.500	1.0120	1.0106	1.0096	1.0087	1.0080	1.0068	1.0060	1.0048	1.0040	1.0032	1.0024	1.0019	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0002
1.625	1.0110	1.0098	1.0088	1.0080	1.0073	1.0063	1.0055	1.0044	1.0037	1.0029	1.0022	1.0018	1.0015	1.0013	1.0011	1.0009	1.0006	1.0004	1.0002
1.750	1.0101	1.0090	1.0081	1.0073	1.0067	1.0058	1.0050	1.0040	1.0034	1.0027	1.0020	1.0016	1.0013	1.0012	1.0010	1.0008	1.0006	1.0004	1.0002
1.875	1.0093	1.0082	1.0074	1.0067	1.0062	1.0053	1.0046	1.0037	1.0031	1.0025	1.0019	1.0015	1.0012	1.0011	1.0009	1.0007	1.0005	1.0004	1.0002
2.000	1.0086	1.0076	1.0069	1.0062	1.0057	1.0049	1.0043	1.0034	1.0029	1.0023	1.0017	1.0014	1.0011	1.0010	1.0009	1.0007	1.0005	1.0003	1.0002
2.125	1.0080	1.0071	1.0064	1.0058	1.0053	1.0045	1.0040	1.0032	1.0027	1.0021	1.0016	1.0013	1.0011	1.0009	1.0008	1.0006	1.0005	1.0003	1.0002
2.250	1.0074	1.0066	1.0059	1.0054	1.0050	1.0042	1.0037	1.0030	1.0025	1.0020	1.0015	1.0012	1.0010	1.0008	1.0007	1.0006	1.0004	1.0003	1.0002
2.375	1.0070	1.0062	1.0056	1.0051	1.0047	1.0040	1.0035	1.0028	1.0023	1.0019	1.0014	1.0011	1.0009	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
2.500	1.0056	1.0059	1.0053	1.0048	1.0044	1.0038	1.0033	1.0026	1.0022	1.0018	1.0013	1.0011	1.0009	1.0008	1.0007	1.0005	1.0004	1.0003	1.0001
2.625	1.0064	1.0056	1.0051	1.0046	1.0042	1.0036	1.0032	1.0025	1.0021	1.0017	1.0013	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0001
2.750	1.0061	1.0055	1.0049	1.0045	1.0041	1.0035	1.0031	1.0025	1.0020	1.0016	1.0012	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0002	1.0001
2.875	1.0060	1.0053	1.0048	1.0044	1.0040	1.0034	1.0030	1.0024	1.0020	1.0016	1.0012	1.0010	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
3.000	1.0059	1.0053	1.0047	1.0043	1.0040	1.0034	1.0030	1.0024	1.0020	1.0016	1.0012	1.0009	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
3.125	1.0059	1.0053	1.0047	1.0043	1.0040	1.0034	1.0030	1.0024	1.0020	1.0016	1.0012	1.0009	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
3.250	1.0060	1.0053	1.0048	1.0044	1.0040	1.0034	1.0030	1.0024	1.0020	1.0016	1.0012	1.0010	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
3.375	1.0061	1.0054	1.0049	1.0044	1.0041	1.0035	1.0031	1.0024	1.0020	1.0016	1.0012	1.0010	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
3.500	1.0063	1.0056	1.0050	1.0046	1.0042	1.0036	1.0031	1.0025	1.0021	1.0017	1.0013	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0001
3.625	1.0065	1.0058	1.0052	1.0047	1.0043	1.0037	1.0033	1.0026	1.0022	1.0017	1.0013	1.0010	1.0009	1.0007	1.0007	1.0005	1.0004	1.0003	1.0001
3.750	1.0068	1.0060	1.0054	1.0049	1.0045	1.0039	1.0034	1.0027	1.0023	1.0018	1.0014	1.0011	1.0009	1.0008	1.0007	1.0005	1.0004	1.0003	1.0001
3.875	1.0071	1.0063	1.0057	1.0051	1.0047	1.0040	1.0035	1.0028	1.0024	1.0019	1.0014	1.0011	1.0009	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
4.000	1.0074	1.0066	1.0060	1.0054	1.0050	1.0042	1.0037	1.0030	1.0025	1.0020	1.0015	1.0012	1.0010	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
4.250	1.0082	1.0073	1.0066	1.0060	1.0055	1.0047	1.0041	1.0033	1.0028	1.0022	1.0016	1.0013	1.0011	1.0009	1.0008	1.0007	1.0005	1.0003	1.0002
4.500	1.0091	1.0081	1.0073	1.0067	1.0061	1.0052	1.0046	1.0037	1.0030	1.0024	1.0018	1.0015	1.0012	1.0010	1.0009	1.0007	1.0005	1.0004	1.0002
4.750	1.0101	1.0090	1.0081	1.0074	1.0068	1.0058	1.0051	1.0041	1.0034	1.0027	1.0020	1.0016	1.0014	1.0012	1.0010	1.0008	1.0006	1.0004	1.0002
5.000	1.0112	1.0099	1.0089	1.0081	1.0074	1.0064	1.0056	1.0045	1.0037	1.0030	1.0022	1.0018	1.0015	1.0013	1.0011	1.0009	1.0006	1.0004	1.0002
5.250	1.0122	1.0108	1.0097	1.0089	1.0081	1.0070	1.0061	1.0049	1.0041	1.0032	1.0024	1.0019	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0002
5.500	1.0131	1.0117	1.0105	1.0095	1.0088	1.0075	1.0066	1.0053	1.0044	1.0035	1.0026	1.0021	1.0018	1.0015	1.0013	1.0011	1.0008	1.0005	1.0003
5.750	1.0140	1.0124	1.0112	1.0102	1.0093	1.0080	1.0070	1.0056	1.0047	1.0037	1.0028	1.0022	1.0019	1.0016	1.0014	1.0011	1.0008	1.0006	1.0003
6.000	1.0147	1.0131	1.0118	1.0107	1.0098	1.0084	1.0074	1.0059	1.0049	1.0039	1.0029	1.0024	1.0020	1.0017	1.0015	1.0012	1.0008	1.0006	1.0003

For 10″ Line

Orifice Diam. Inches	$\sqrt{h_w p_f}$																		
	4.0	4.5	5.0	5.5	6.0	7.0	8.0	10	12	15	20	25	30	35	40	50	70	100	200
1.125	1.0176	1.0157	1.0141	1.0128	1.0118	1.0101	1.0088	1.0071	1.0059	1.0047	1.0035	1.0028	1.0024	1.0020	1.0018	1.0014	1.0010	1.0007	1.0004
1.250	1.0164	1.0146	1.0131	1.0119	1.0109	1.0094	1.0082	1.0066	1.0055	1.0044	1.0033	1.0026	1.0022	1.0019	1.0016	1.0013	1.0009	1.0007	1.0003
1.375	1.0153	1.0136	1.0122	1.0111	1.0102	1.0087	1.0076	1.0061	1.0051	1.0041	1.0031	1.0024	1.0020	1.0017	1.0015	1.0012	1.0009	1.0006	1.0003
1.500	1.0142	1.0126	1.0114	1.0103	1.0095	1.0081	1.0071	1.0057	1.0047	1.0038	1.0028	1.0023	1.0019	1.0016	1.0014	1.0011	1.0008	1.0006	1.0003
1.625	1.0132	1.0117	1.0106	1.0096	1.0088	1.0075	1.0066	1.0053	1.0044	1.0035	1.0026	1.0021	1.0018	1.0015	1.0013	1.0011	1.0008	1.0005	1.0003
1.750	1.0122	1.0109	1.0098	1.0089	1.0082	1.0070	1.0061	1.0049	1.0041	1.0033	1.0024	1.0020	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0002
1.875	1.0114	1.0101	1.0091	1.0083	1.0076	1.0065	1.0057	1.0046	1.0038	1.0030	1.0023	1.0018	1.0015	1.0013	1.0011	1.0009	1.0007	1.0005	1.0002
2.000	1.0106	1.0094	1.0085	1.0077	1.0071	1.0060	1.0053	1.0042	1.0035	1.0028	1.0021	1.0017	1.0014	1.0012	1.0011	1.0008	1.0006	1.0004	1.0002
2.125	1.0098	1.0087	1.0079	1.0072	1.0066	1.0056	1.0049	1.0039	1.0033	1.0026	1.0020	1.0016	1.0013	1.0011	1.0010	1.0008	1.0006	1.0004	1.0002
2.250	1.0091	1.0081	1.0073	1.0067	1.0061	1.0052	1.0046	1.0037	1.0030	1.0024	1.0018	1.0015	1.0012	1.0010	1.0009	1.0007	1.0005	1.0004	1.0002
2.375	1.0085	1.0076	1.0068	1.0062	1.0057	1.0049	1.0043	1.0034	1.0028	1.0023	1.0017	1.0014	1.0011	1.0010	1.0009	1.0007	1.0005	1.0003	1.0002
2.500	1.0080	1.0071	1.0064	1.0058	1.0053	1.0046	1.0040	1.0032	1.0027	1.0021	1.0016	1.0013	1.0011	1.0009	1.0008	1.0006	1.0005	1.0003	1.0002
2.625	1.0075	1.0066	1.0060	1.0054	1.0050	1.0043	1.0037	1.0030	1.0025	1.0020	1.0015	1.0012	1.0010	1.0009	1.0008	1.0006	1.0004	1.0003	1.0001
2.750	1.0070	1.0062	1.0056	1.0051	1.0047	1.0040	1.0035	1.0028	1.0023	1.0019	1.0014	1.0011	1.0009	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
2.875	1.0066	1.0059	1.0053	1.0048	1.0044	1.0038	1.0033	1.0027	1.0022	1.0018	1.0013	1.0011	1.0009	1.0008	1.0007	1.0005	1.0004	1.0003	1.0001
3.000	1.0063	1.0056	1.0050	1.0046	1.0042	1.0036	1.0032	1.0025	1.0021	1.0017	1.0013	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0001
3.125	1.0060	1.0053	1.0048	1.0044	1.0040	1.0034	1.0030	1.0024	1.0020	1.0016	1.0012	1.0010	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
3.250	1.0058	1.0051	1.0046	1.0042	1.0039	1.0033	1.0029	1.0023	1.0019	1.0015	1.0012	1.0009	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
3.375	1.0056	1.0050	1.0045	1.0041	1.0037	1.0032	1.0028	1.0022	1.0019	1.0015	1.0011	1.0009	1.0007	1.0006	1.0006	1.0004	1.0003	1.0002	1.0001
3.500	1.0054	1.0048	1.0044	1.0040	1.0036	1.0031	1.0027	1.0022	1.0018	1.0015	1.0011	1.0009	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
3.625	1.0054	1.0048	1.0043	1.0039	1.0036	1.0031	1.0027	1.0021	1.0018	1.0014	1.0011	1.0009	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
3.750	1.0053	1.0047	1.0042	1.0039	1.0035	1.0030	1.0026	1.0021	1.0018	1.0014	1.0011	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
3.875	1.0053	1.0047	1.0042	1.0038	1.0035	1.0030	1.0026	1.0021	1.0018	1.0014	1.0011	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
4.000	1.0053	1.0047	1.0043	1.0039	1.0035	1.0030	1.0027	1.0021	1.0018	1.0014	1.0011	1.0009	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
4.250	1.0055	1.0049	1.0044	1.0040	1.0037	1.0031	1.0027	1.0022	1.0018	1.0015	1.0011	1.0009	1.0007	1.0006	1.0006	1.0004	1.0003	1.0002	1.0001
4.500	1.0058	1.0051	1.0046	1.0042	1.0039	1.0033	1.0029	1.0023	1.0019	1.0015	1.0012	1.0009	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
4.750	1.0062	1.0055	1.0050	1.0045	1.0041	1.0035	1.0031	1.0025	1.0021	1.0017	1.0012	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0002	1.0001
5.000	1.0068	1.0060	1.0054	1.0049	1.0045	1.0039	1.0034	1.0027	1.0022	1.0018	1.0014	1.0011	1.0009	1.0008	1.0007	1.0005	1.0004	1.0003	1.0001
5.250	1.0074	1.0066	1.0059	1.0054	1.0049	1.0042	1.0037	1.0030	1.0025	1.0020	1.0015	1.0012	1.0010	1.0038	1.0007	1.0006	1.0004	1.0003	1.0001
5.500	1.0081	1.0072	1.0065	1.0059	1.0054	1.0046	1.0040	1.0032	1.0027	1.0022	1.0016	1.0013	1.0011	1.0039	1.0008	1.0006	1.0005	1.0003	1.0002
5.750	1.0088	1.0079	1.0071	1.0064	1.0059	1.0051	1.0044	1.0035	1.0029	1.0024	1.0018	1.0014	1.0012	1.0010	1.0009	1.0007	1.0005	1.0004	1.0002
6.000	1.0096	1.0086	1.0077	1.0070	1.0064	1.0055	1.0048	1.0039	1.0032	1.0026	1.0019	1.0015	1.0013	1.0011	1.0010	1.0008	1.0006	1.0004	1.0002
6.250	1.0105	1.0093	1.0084	1.0076	1.0070	1.0060	1.0052	1.0042	1.0035	1.0028	1.0021	1.0017	1.0014	1.0012	1.0010	1.0008	1.0006	1.0004	1.0002
6.500	1.0113	1.0100	1.0090	1.0082	1.0075	1.0064	1.0056	1.0045	1.0038	1.0030	1.0023	1.0018	1.0015	1.0013	1.0011	1.0009	1.0006	1.0005	1.0002
6.750	1.0121	1.0107	1.0097	1.0088	1.0080	1.0069	1.0060	1.0048	1.0040	1.0032	1.0024	1.0019	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0002
7.000	1.0128	1.0114	1.0103	1.0093	1.0086	1.0073	1.0064	1.0051	1.0043	1.0034	1.0026	1.0021	1.0017	1.0015	1.0013	1.0010	1.0007	1.0005	1.0003
7.250	1.0135	1.0120	1.0108	1.0098	1.0090	1.0077	1.0068	1.0054	1.0045	1.0036	1.0027	1.0022	1.0018	1.0015	1.0014	1.0011	1.0008	1.0005	1.0003
7.500	1.0141	1.0126	1.0113	1.0103	1.0094	1.0081	1.0071	1.0056	1.0047	1.0038	1.0028	1.0023	1.0019	1.0016	1.0014	1.0011	1.0008	1.0006	1.0003

TABLE 6 — Continued

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REYNOLDS' NUMBER FACTORS — FLANGE TAPS

For 12" Line

Orifice Diam. Inches	$\sqrt{h_w p_f}$																		
	4.0	4.5	5.0	5.5	6.0	7.0	8.0	10	12	15	20	25	30	35	40	50	70	100	200
1.250	1.0180	1.0160	1.0144	1.0131	1.0120	1.0103	1.0090	1.0072	1.0060	1.0048	1.0036	1.0029	1.0024	1.0021	1.0018	1.0014	1.0010	1.0007	1.0004
1.375	1.0169	1.0150	1.0135	1.0123	1.0113	1.0097	1.0085	1.0068	1.0056	1.0045	1.0034	1.0027	1.0023	1.0019	1.0017	1.0014	1.0010	1.0007	1.0003
1.500	1.0159	1.0141	1.0127	1.0116	1.0106	1.0091	1.0079	1.0064	1.0053	1.0042	1.0032	1.0025	1.0021	1.0018	1.0016	1.0013	1.0009	1.0006	1.0003
1.625	1.0149	1.0133	1.0119	1.0109	1.0100	1.0085	1.0075	1.0060	1.0050	1.0040	1.0030	1.0024	1.0020	1.0017	1.0015	1.0012	1.0009	1.0006	1.0003
1.750	1.0140	1.0125	1.0112	1.0102	1.0093	1.0080	1.0070	1.0056	1.0047	1.0037	1.0028	1.0022	1.0019	1.0016	1.0014	1.0011	1.0008	1.0006	1.0003
1.875	1.0132	1.0117	1.0105	1.0096	1.0088	1.0075	1.0066	1.0053	1.0044	1.0035	1.0026	1.0021	1.0018	1.0015	1.0013	1.0011	1.0008	1.0005	1.0003
2.000	1.0123	1.0110	1.0099	1.0090	1.0082	1.0070	1.0062	1.0049	1.0041	1.0033	1.0025	1.0020	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0002
2.125	1.0116	1.0103	1.0093	1.0084	1.0077	1.0066	1.0058	1.0046	1.0039	1.0031	1.0023	1.0019	1.0015	1.0013	1.0012	1.0009	1.0007	1.0005	1.0002
2.250	1.0109	1.0096	1.0087	1.0079	1.0072	1.0062	1.0054	1.0043	1.0036	1.0029	1.0022	1.0017	1.0014	1.0012	1.0011	1.0009	1.0006	1.0004	1.0002
2.375	1.0102	1.0090	1.0081	1.0074	1.0068	1.0058	1.0051	1.0041	1.0034	1.0027	1.0020	1.0016	1.0014	1.0012	1.0010	1.0008	1.0006	1.0004	1.0002
2.500	1.0096	1.0085	1.0076	1.0069	1.0064	1.0055	1.0048	1.0038	1.0032	1.0025	1.0019	1.0015	1.0013	1.0011	1.0010	1.0008	1.0005	1.0004	1.0002
2.625	1.0090	1.0080	1.0072	1.0065	1.0060	1.0051	1.0045	1.0036	1.0030	1.0024	1.0018	1.0014	1.0012	1.0010	1.0009	1.0007	1.0005	1.0004	1.0002
2.750	1.0084	1.0075	1.0067	1.0061	1.0056	1.0048	1.0042	1.0034	1.0028	1.0022	1.0017	1.0013	1.0011	1.0010	1.0008	1.0007	1.0005	1.0003	1.0002
2.875	1.0079	1.0070	1.0063	1.0058	1.0053	1.0045	1.0040	1.0032	1.0026	1.0021	1.0016	1.0013	1.0011	1.0009	1.0008	1.0006	1.0005	1.0003	1.0002
3.000	1.0075	1.0066	1.0060	1.0054	1.0050	1.0043	1.0037	1.0030	1.0025	1.0020	1.0015	1.0012	1.0010	1.0009	1.0007	1.0006	1.0004	1.0003	1.0001
3.125	1.0070	1.0063	1.0056	1.0051	1.0047	1.0040	1.0035	1.0028	1.0023	1.0019	1.0014	1.0011	1.0009	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
3.250	1.0067	1.0059	1.0053	1.0048	1.0044	1.0038	1.0033	1.0027	1.0022	1.0018	1.0013	1.0011	1.0009	1.0008	1.0007	1.0005	1.0004	1.0003	1.0001
3.375	1.0063	1.0056	1.0051	1.0046	1.0042	1.0036	1.0032	1.0025	1.0021	1.0017	1.0013	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0001
3.500	1.0060	1.0054	1.0048	1.0044	1.0040	1.0034	1.0030	1.0024	1.0020	1.0016	1.0012	1.0010	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
3.625	1.0058	1.0051	1.0046	1.0042	1.0038	1.0033	1.0029	1.0023	1.0019	1.0015	1.0012	1.0009	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
3.750	1.0055	1.0049	1.0044	1.0040	1.0037	1.0032	1.0028	1.0022	1.0018	1.0015	1.0011	1.0009	1.0007	1.0006	1.0006	1.0004	1.0003	1.0002	1.0001
3.875	1.0053	1.0047	1.0043	1.0039	1.0036	1.0030	1.0027	1.0021	1.0018	1.0014	1.0011	1.0009	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
4.000	1.0052	1.0046	1.0041	1.0038	1.0034	1.0030	1.0026	1.0021	1.0017	1.0014	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
4.250	1.0049	1.0044	1.0040	1.0036	1.0033	1.0028	1.0025	1.0020	1.0016	1.0013	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
4.500	1.0048	1.0043	1.0039	1.0035	1.0032	1.0028	1.0024	1.0019	1.0016	1.0013	1.0010	1.0008	1.0006	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
4.750	1.0049	1.0043	1.0039	1.0035	1.0032	1.0028	1.0024	1.0019	1.0016	1.0013	1.0010	1.0008	1.0006	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
5.000	1.0050	1.0044	1.0040	1.0036	1.0033	1.0028	1.0025	1.0020	1.0017	1.0013	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
5.250	1.0052	1.0046	1.0042	1.0038	1.0035	1.0030	1.0026	1.0021	1.0017	1.0014	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
5.500	1.0055	1.0049	1.0044	1.0040	1.0037	1.0032	1.0028	1.0022	1.0018	1.0015	1.0011	1.0009	1.0007	1.0006	1.0006	1.0004	1.0003	1.0002	1.0001
5.750	1.0059	1.0053	1.0047	1.0043	1.0039	1.0034	1.0030	1.0024	1.0020	1.0016	1.0012	1.0009	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
6.000	1.0064	1.0057	1.0051	1.0046	1.0043	1.0036	1.0032	1.0026	1.0021	1.0017	1.0013	1.0010	1.0009	1.0007	1.0006	1.0005	1.0004	1.0003	1.0001
6.250	1.0069	1.0061	1.0055	1.0050	1.0046	1.0040	1.0035	1.0028	1.0023	1.0018	1.0014	1.0011	1.0009	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
6.500	1.0075	1.0067	1.0060	1.0055	1.0050	1.0043	1.0038	1.0030	1.0025	1.0020	1.0015	1.0012	1.0010	1.0009	1.0008	1.0006	1.0004	1.0003	1.0002
6.750	1.0081	1.0072	1.0065	1.0059	1.0054	1.0046	1.0041	1.0033	1.0027	1.0022	1.0016	1.0013	1.0011	1.0009	1.0008	1.0007	1.0005	1.0003	1.0002
7.000	1.0088	1.0078	1.0070	1.0064	1.0059	1.0050	1.0044	1.0035	1.0029	1.0023	1.0018	1.0014	1.0012	1.0010	1.0009	1.0007	1.0005	1.0004	1.0002
7.250	1.0095	1.0084	1.0076	1.0069	1.0063	1.0054	1.0047	1.0038	1.0032	1.0025	1.0019	1.0015	1.0013	1.0011	1.0009	1.0008	1.0005	1.0004	1.0002
7.500	1.0102	1.0090	1.0081	1.0074	1.0068	1.0058	1.0051	1.0041	1.0034	1.0027	1.0020	1.0016	1.0014	1.0012	1.0010	1.0008	1.0006	1.0004	1.0002
7.750	1.0108	1.0096	1.0087	1.0079	1.0072	1.0062	1.0054	1.0043	1.0036	1.0029	1.0022	1.0017	1.0014	1.0012	1.0011	1.0009	1.0006	1.0004	1.0002
8.000	1.0115	1.0102	1.0092	1.0084	1.0077	1.0066	1.0058	1.0046	1.0038	1.0031	1.0023	1.0018	1.0015	1.0013	1.0012	1.0009	1.0007	1.0005	1.0002
8.250	1.0122	1.0108	1.0097	1.0089	1.0081	1.0070	1.0061	1.0049	1.0041	1.0032	1.0024	1.0019	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0002
8.500	1.0128	1.0114	1.0102	1.0093	1.0085	1.0073	1.0064	1.0051	1.0043	1.0034	1.0026	1.0020	1.0017	1.0015	1.0013	1.0010	1.0007	1.0005	1.0003
8.750	1.0133	1.0119	1.0107	1.0097	1.0089	1.0076	1.0067	1.0053	1.0044	1.0036	1.0027	1.0021	1.0018	1.0015	1.0013	1.0011	1.0008	1.0005	1.0003
9.000	1.0138	1.0123	1.0111	1.0101	1.0092	1.0079	1.0069	1.0055	1.0046	1.0037	1.0028	1.0022	1.0018	1.0016	1.0014	1.0011	1.0008	1.0006	1.0003

TABLE 8-A Y_1 EXPANSION FACTORS — FLANGE TAPS

Static Pressure Taken from Upstream Taps

Line Size	ORIFICE SIZES																											
2"	1/8" 1/4"	3/8" 1/2"	5/8"	3/4"	7/8"	1"		1 1/8"				1 1/4"					1 3/8"							1 1/2"		
3"	1/8" 3/8"	1/2" 3/4"	7/8" 1"	1 1/8" 1 1/4"	1 3/8"	1 1/2"		1 5/8"		1 3/4"		1 7/8"				2"				2 1/8"				2 1/4"		
4"	1/8" 1/2"	5/8" 1"	1 1/4" 1 3/8"	1 1/2" 1 5/8"	1 3/4" 1 7/8"	2"	2 1/8"		2 1/4"	2 3/8"			2 1/2"			2 5/8"			2 3/4"			2 7/8"			3"	
6"	1/8" 7/8"	1" 1 1/2"	1 5/8" 2"	2 1/8" 2 1/2"	2 5/8" 2 7/8"	3"	3 1/8"	3 1/4"	3 3/8"	3 1/2"	3 5/8"		3 3/4"		3 7/8"		4"				4 1/4"				4 1/2"	
8"	1/8" 1 1/8"	1 1/4" 2"	2 1/8" 2 3/4"	2 7/8" 3 3/8"	3 1/2" 3 3/4"	3 7/8" 4"	4 1/4"		4 1/2"	4 3/4"			5"			5 1/4"			5 1/2"			5 3/4"			6"	
10"	1/8" 1 1/2"	1 5/8" 2 1/2"	2 5/8" 3 1/2"	3 5/8" 4 1/4"	4 1/2" 4 3/4"	5"	5 1/4"	5 1/2"	5 3/4"		6"		6 1/4"		6 1/2"			6 3/4"		7"		7 1/4"			7 1/2"	
12"	1/8" 1 3/4"	1 7/8" 3"	3 1/8" 4"	4 1/4" 5"	5 1/4" 5 1/2"	5 3/4" 6"	6 1/4"	6 1/2"	6 3/4"	7"	7 1/4"		7 1/2"		7 3/4"		8"		8 1/4"		8 1/2"		8 3/4"		9"	
15 1/4"	1/8" 2 1/4"	2 1/2" 3 3/4"	3 7/8" 5 1/4"	5 1/2" 6 1/4"	6 1/2" 7 1/4"	7 1/2" 7 3/4"	8"	8 1/4"	8 1/2"	8 3/4"	9"	9 1/4"	9 1/2"		9 3/4"		10"	10 1/4"		10 1/2"	10 3/4"		11"		11 1/4"	
$\frac{h_w}{p_1}$													$\beta = \frac{D_2}{D_1}$ Ratio														
Ratio	.1	.2	.3	.4	.45	.50	.52	.54	.56	.58	.60	.61	.62	.63	.64	.65	.66	.67	.68	.69	.70	.71	.72	.73	.74	.75
0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.1	.9989	.9989	.9989	.9988	.9988	.9988	.9988	.9988	.9988	.9988	.9987	.9987	.9987	.9987	.9987	.9987	.9987	.9987	.9987	.9986	.9986	.9986	.9986	.9986	.9986	.9986
0.2	.9977	.9977	.9977	.9977	.9976	.9976	.9976	.9976	.9975	.9975	.9975	.9975	.9974	.9974	.9974	.9974	.9974	.9973	.9973	.9973	.9973	.9972	.9972	.9972	.9971	.9971
0.3	.9966	.9966	.9966	.9965	.9965	.9964	.9964	.9963	.9963	.9963	.9962	.9962	.9962	.9961	.9961	.9961	.9960	.9960	.9960	.9959	.9959	.9958	.9958	.9958	.9957	.9957
0.4	.9954	.9954	.9954	.9953	.9953	.9952	.9952	.9951	.9951	.9950	.9949	.9949	.9949	.9948	.9948	.9948	.9947	.9947	.9946	.9946	.9945	.9945	.9944	.9943	.9943	.9942
0.5	.9943	.9943	.9943	.9942	.9941	.9940	.9940	.9939	.9938	.9938	.9937	.9936	.9936	.9935	.9935	.9934	.9934	.9933	.9933	.9932	.9931	.9931	.9930	.9929	.9929	.9928
0.6	.9932	.9932	.9931	.9930	.9929	.9928	.9927	.9927	.9926	.9925	.9924	.9924	.9923	.9923	.9922	.9921	.9921	.9920	.9919	.9918	.9918	.9917	.9916	.9915	.9914	.9913
0.7	.9920	.9920	.9920	.9919	.9918	.9916	.9915	.9915	.9914	.9913	.9912	.9911	.9910	.9910	.9909	.9908	.9907	.9907	.9906	.9905	.9904	.9903	.9902	.9901	.9900	.9899
0.8	.9909	.9909	.9908	.9907	.9906	.9904	.9903	.9902	.9901	.9900	.9899	.9898	.9897	.9897	.9896	.9895	.9894	.9893	.9892	.9891	.9890	.9889	.9888	.9887	.9886	.9884
0.9	.9898	.9897	.9397	.9895	.9894	.9892	.9891	.9890	.9889	.9888	.9986	.9885	.9885	.9884	.9883	.9882	.9381	.9880	.9879	.9878	.9877	.9875	.9874	.9873	.9871	.9870
1.0	.9886	.9886	.9885	.9884	.9882	.9880	.9879	.9878	.9877	.9875	.9874	.9873	.9872	.9871	.9870	.9869	.9868	.9867	.9865	.9864	.9863	.9861	.9860	.9859	.9857	.9855
1.1	.9875	.9875	.9874	.9872	.9870	.9868	.9867	.9866	.9864	.9863	.9861	.9860	.9859	.9858	.9857	.9856	.9854	.9853	.9852	.9851	.9849	.9848	.9846	.9844	.9843	.9841
1.2	.9863	.9863	.9862	.9860	.9859	.9856	.9855	.9853	.9852	.9850	.9848	.9847	.9846	.9845	.9844	.9843	.9841	.9840	.9838	.9837	.9835	.9834	.9832	.9830	.9828	.9826
1.3	.9852	.9852	.9851	.9849	.9847	.9844	.9843	.9841	.9840	.9838	.9836	.9835	.9833	.9832	.9831	.9829	.9828	.9827	.9825	.9823	.9822	.9820	.9818	.9816	.9814	.9812
1.4	.9841	.9840	.9840	.9837	.9835	.9832	.9831	.9829	.9827	.9825	.9823	.9822	.9821	.9819	.9818	.9816	.9815	.9813	.9812	.9810	.9808	.9806	.9804	.9802	.9800	.9798
1.5	.9829	.9829	.9828	.9826	.9823	.9820	.9819	.9817	.9815	.9813	.9810	.9809	.9808	.9306	.9805	.9803	.9802	.9800	.9798	.9796	.9794	.9792	.9790	.9788	.9786	.9783
1.6	.9818	.9818	.9817	.9814	.9811	.9808	.9306	.9805	.9803	.9800	.9798	.9796	.9795	.9793	.9792	.9790	.9788	.9787	.9785	.9783	.9781	.9778	.9776	.9774	.9771	.9769
1.7	.9806	.9806	.9805	.9802	.9800	.9796	.9794	.9792	.9790	.9788	.9785	.9784	.9782	.9780	.9779	.9777	.9775	.9773	.9771	.9769	.9767	.9764	.9762	.9760	.9757	.9754
1.8	.9795	.9795	.9794	.9791	.9788	.9784	.9782	.9780	.9778	.9775	.9772	.9771	.9769	.9768	.9766	.9764	.9762	.9760	.9758	.9755	.9753	.9751	.9748	.9745	.9743	.9740
1.9	.9784	.9783	.9782	.9779	.9776	.9772	.9770	.9768	.9766	.9763	.9760	.9758	.9756	.9755	.9753	.9751	.9749	.9747	.9744	.9742	.9739	.9737	.9734	.9731	.9728	.9725
2.0	.9772	.9772	.9771	.9767	.9764	.9760	.9758	.9756	.9753	.9750	.9747	.9745	.9744	.9742	.9740	.9738	.9735	.9733	.9731	.9728	.9726	.9723	.9720	.9717	.9714	.9711
2.1	.9761	.9761	.9759	.9756	.9753	.9748	.9746	.9744	.9741	.9738	.9734	.9733	.9731	.9729	.9727	.9725	.9722	.9720	.9717	.9715	.9712	.9709	.9706	.9703	.9700	.9696
2.2	.9750	.9749	.9748	.9744	.9741	.9736	.9734	.9731	.9729	.9725	.9722	.9720	.9718	.9716	.9714	.9711	.9709	.9706	.9704	.9701	.9698	.9695	.9692	.9689	.9685	.9682
2.3	.9738	.9738	.9736	.9732	.9729	.9724	.9722	.9719	.9716	.9713	.9709	.9707	.9705	.9703	.9701	.9698	.9696	.9693	.9690	.9688	.9685	.9681	.9678	.9675	.9671	.9667
2.4	.9727	.9726	.9725	.9721	.9717	.9712	.9710	.9707	.9704	.9700	.9697	.9694	.9692	.9690	.9688	.9685	.9683	.9680	.9677	.9674	.9671	.9668	.9664	.9661	.9657	.9653
2.5	.9715	.9715	.9713	.9709	.9705	.9700	.9698	.9695	.9692	.9688	.9684	.9682	.9680	.9677	.9675	.9672	.9669	.9666	.9663	.9660	.9657	.9654	.9650	.9646	.9643	.9639
2.6	.9704	.9704	.9702	.9698	.9694	.9688	.9686	.9683	.9679	.9675	.9671	.9669	.9667	.9664	.9662	.9659	.9656	.9653	.9650	.9647	.9643	.9640	.9636	.9632	.9628	.9624
2.7	.9693	.9692	.9691	.9686	.9682	.9676	.9673	.9670	.9667	.9663	.9659	.9656	.9654	.9651	.9649	.9646	.9643	.9640	.9637	.9633	.9630	.9626	.9622	.9618	.9614	.9610
2.8	.9681	.9681	.9679	.9674	.9670	.9664	.9661	.9658	.9654	.9650	.9646	.9644	.9641	.9638	.9636	.9633	.9630	.9626	.9623	.9620	.9616	.9612	.9608	.9604	.9600	.9595
2.9	.9670	.9669	.9668	.9663	.9658	.9652	.9649	.9646	.9642	.9638	.9633	.9631	.9628	.9625	.9623	.9620	.9616	.9613	.9610	.9606	.9602	.9598	.9594	.9590	.9585	.9581
3.0	.9658	.9658	.9656	.9651	.9647	.9640	.9637	.9634	.9630	.9626	.9621	.9618	.9615	.9613	.9610	.9606	.9603	.9600	.9596	.9592	.9588	.9584	.9580	.9576	.9571	.9566
3.1	.9647	.9647	.9645	.9639	.9635	.9628	.9625	.9622	.9617	.9613	.9608	.9605	.9603	.9600	.9597	.9593	.9590	.9586	.9583	.9579	.9575	.9571	.9566	.9562	.9557	.9552
3.2	.9636	.9635	.9633	.9628	.9623	.9616	.9613	.9609	.9605	.9601	.9595	.9593	.9590	.9587	.9584	.9580	.9577	.9573	.9569	.9565	.9561	.9557	.9552	.9547	.9542	.9537
3.3	.9624	.9624	.9622	.9616	.9611	.9604	.9601	.9597	.9593	.9588	.9583	.9580	.9577	.9574	.9571	.9567	.9564	.9560	.9556	.9552	.9547	.9543	.9538	.9533	.9528	.9523
3.4	.9613	.9612	.9610	.9604	.9599	.9592	.9589	.9585	.9580	.9576	.9570	.9567	.9564	.9561	.9558	.9554	.9550	.9546	.9542	.9538	.9534	.9529	.9524	.9519	.9514	.9508
3.5	.9602	.9601	.9599	.9593	.9588	.9580	.9577	.9573	.9568	.9563	.9558	.9554	.9551	.9548	.9545	.9541	.9537	.9533	.9529	.9524	.9520	.9515	.9510	.9505	.9500	.9494
3.6	.9590	.9590	.9587	.9581	.9576	.9568	.9565	.9560	.9556	.9551	.9545	.9542	.9538	.9535	.9532	.9528	.9524	.9520	.9515	.9511	.9506	.9501	.9496	.9491	.9485	.9480
3.7	.9579	.9578	.9576	.9570	.9564	.9556	.9553	.9548	.9543	.9538	.9532	.9529	.9526	.9522	.9518	.9515	.9511	.9506	.9502	.9497	.9492	.9487	.9482	.9477	.9471	.9465
3.8	.9567	.9567	.9564	.9558	.9552	.9544	.9540	.9536	.9531	.9526	.9520	.9516	.9513	.9509	.9505	.9502	.9497	.9493	.9488	.9484	.9479	.9474	.9468	.9463	.9457	.9451
3.9	.9556	.9555	.9553	.9546	.9540	.9532	.9528	.9524	.9519	.9513	.9507	.9504	.9500	.9496	.9492	.9488	.9484	.9480	.9475	.9470	.9465	.9460	.9454	.9448	.9442	.9436
4.0	.9545	.9544	.9542	.9535	.9529	.9520	.9516	.9512	.9506	.9501	.9494	.9491	.9487	.9483	.9479	.9475	.9471	.9465	.9462	.9457	.9451	.9446	.9440	.9434	.9428	.9422

NOTE: Above tables are for use on natural gas and are based on ratio of specific heats equal to 1.30.

TABLE 9-A Y_2 EXPANSION FACTORS — FLANGE TAPS

Static Pressure Taken from Downstream Taps

Line Size	ORIFICE SIZES																										
2"	1/8" 1/4"	3/8" 1/2"	5/8"	3/4"	7/8"	1"		1 1/8"				1 1/4"					1 3/8"							1 1/2"		
3"	1/8" 3/8"	1/2" 3/4"	7/8" 1"	1 1/8" 1 1/4"	1 3/8"	1 1/2"		1 5/8"		1 3/4"		1 7/8"				2"				2 1/8"				2 1/4"		
4"	1/8" 1/2"	5/8" 1"	1 1/8" 1 3/8"	1 1/2" 1 5/8"	1 3/4" 1 7/8"	2"	2 1/8"		2 1/4"	2 3/8"			2 1/2"			2 5/8"			2 3/4"			2 7/8"			3"	
6"	1/8" 7/8"	1" 1 1/2"	1 5/8" 2"	2 1/8" 2 1/2"	2 5/8" 2 7/8"	3"	3 1/8"	3 1/4"	3 3/8"	3 1/2"	3 5/8"		3 3/4"		3 7/8"		4"				4 1/4"				4 1/2"	
8"	1/8" 1 1/8"	1 1/4" 2"	2 1/8" 2 3/4"	2 7/8" 3 3/8"	3 1/2" 3 3/4"	3 7/8" 4"	4 1/4"		4 1/2"	4 3/4"			5"			5 1/4"			5 1/2"			5 3/4"			6"	
10"	1/8" 1 1/2"	1 5/8" 2 1/2"	2 5/8" 3 1/2"	3 5/8" 4 1/4"	4 1/2" 4 3/4"	5"	5 1/4"	5 1/2"	5 3/4"		6"		6 1/4"		6 1/2"			6 3/4"		7"		7 1/4"			7 1/2"	
12"	1/8" 1 3/4"	1 7/8" 3"	3 1/8" 4"	4 1/4" 5"	5 1/4" 5 1/2"	5 3/4" 6"	6 1/4"	6 1/2"	6 3/4"	7"	7 1/4"		7 1/2"		7 3/4"		8"		8 1/4"		8 1/2"		8 3/4"		9"	
15 1/4"	1/8" 2 1/4"	2 1/2" 3 3/4"	3 7/8" 5 1/4"	5 1/2" 6 1/4"	6 1/2" 7 1/4"	7 1/2" 7 3/4"	8"	8 1/4"	8 1/2"	8 3/4"	9"	9 1/4"	9 1/2"			9 3/4"		10"	10 1/4"		10 1/2"	10 3/4"		11"		11 1/4"	
$\frac{h_w}{p_2}$ Ratio	$\beta = \frac{D_2}{D_1}$, Ratio																										
	.1	.2	.3	.4	.45	.50	.52	.54	.56	.58	.60	.61	.62	.63	.64	.65	.66	.67	.68	.69	.70	.71	.72	.73	.74	.75
0.1	1.0007	1.0007	1.0007	1.0006	1.0006	1.0006	1.0006	1.0006	1.0006	1.0006	1.0005	1.0005	1.0005	1.0005	1.0005	1.0005	1.0005	1.0005	1.0005	1.0004	1.0004	1.0004	1.0004	1.0004	1.0004	1.0004
0.2	1.0013	1.0013	1.0013	1.0013	1.0013	1.0012	1.0012	1.0012	1.0012	1.0011	1.0011	1.0011	1.0011	1.0010	1.0010	1.0010	1.0010	1.0010	1.0009	1.0009	1.0009	1.0008	1.0008	1.0008	1.0008	1.0007
0.3	1.0020	1.0020	1.0020	1.0020	1.0019	1.0018	1.0018	1.0018	1.0017	1.0017	1.0016	1.0016	1.0016	1.0016	1.0015	1.0015	1.0115	1.0014	1.0014	1.0014	1.0013	1.0013	1.0012	1.0012	1.0011	1.0011
0.4	1.0027	1.0027	1.0027	1.0026	1.0026	1.0025	1.0024	1.0024	1.0023	1.0023	1.0022	1.0022	1.0021	1.0021	1.0021	1.0020	1.0020	1.0019	1.0019	1.0018	1.0018	1.0017	1.0017	1.0016	1.0015	1.0015
0.5	1.0033	1.0033	1.0033	1.0032	1.0031	1.0030	1.0029	1.0029	1.0028	1.0028	1.0027	1.0027	1.0027	1.0026	1.0026	1.0025	1.0025	1.0024	1.0024	1.0023	1.0022	1.0022	1.0021	1.0020	1.0019	1.0019
0.6	1.0040	1.0040	1.0040	1.0039	1.0038	1.0036	1.0036	1.0035	1.0034	1.0033	1.0032	1.0032	1.0031	1.0031	1.0030	1.0030	1.0029	1.0028	1.0027	1.0027	1.0026	1.0025	1.0024	1.0023	1.0022	1.0022
0.7	1.0047	1.0047	1.0047	1.0045	1.0044	1.0043	1.0042	1.0041	1.0040	1.0039	1.0038	1.0033	1.0037	1.0036	1.0036	1.0035	1.0034	1.0033	1.0032	1.0031	1.0031	1.0030	1.0029	1.0028	1.0026	1.0025
0.8	1.0053	1.0053	1.0053	1.0051	1.0050	1.0049	1.0048	1.0047	1.0046	1.0045	1.0044	1.0043	1.0043	1.0042	1.0041	1.0040	1.0039	1.0038	1.0037	1.0036	1.0035	1.0034	1.0033	1.0032	1.0031	1.0029
0.9	1.0060	1.0060	1.0060	1.0058	1.0057	1.0055	1.0054	1.0053	1.0052	1.0050	1.0049	1.0048	1.0048	1.0047	1.0046	1.0045	1.0043	1.0042	1.0041	1.0040	1.0039	1.0039	1.0037	1.0036	1.0035	1.0033
1.0	1.0067	1.0066	1.0066	1.0064	1.0063	1.0061	1.0060	1.0059	1.0058	1.0056	1.0055	1.0054	1.0053	1.0052	1.0051	1.0050	1.0049	1.0048	1.0046	1.0045	1.0044	1.0043	1.0041	1.0040	1.0039	1.0037
1.1	1.0074	1.0073	1.0073	1.0071	1.0069	1.0067	1.0066	1.0065	1.0063	1.0061	1.0060	1.0059	1.0058	1.0057	1.0056	1.0055	1.0054	1.0053	1.0051	1.0050	1.0049	1.0047	1.0046	1.0044	1.0042	1.0040
1.2	1.0080	1.0080	1.0079	1.0077	1.0075	1.0073	1.0072	1.0071	1.0069	1.0067	1.0066	1.0065	1.0064	1.0062	1.0061	1.0060	1.0059	1.0057	1.0056	1.0054	1.0053	1.0051	1.0050	1.0048	1.0046	1.0044
1.3	1.0087	1.0087	1.0086	1.0084	1.0082	1.0080	1.0078	1.0077	1.0075	1.0073	1.0071	1.0070	1.0069	1.0067	1.0066	1.0065	1.0064	1.0062	1.0061	1.0059	1.0058	1.0056	1.0054	1.0052	1.0050	1.0048
1.4	1.0094	1.0093	1.0093	1.0090	1.0088	1.0086	1.0084	1.0083	1.0081	1.0079	1.0077	1.0076	1.0074	1.0073	1.0072	1.0070	1.0069	1.0067	1.0065	1.0063	1.0062	1.0060	1.0058	1.0056	1.0054	1.0052
1.5	1.0100	1.0100	1.0099	1.0097	1.0094	1.0091	1.0090	1.0088	1.0086	1.0084	1.0082	1.0081	1.0080	1.0078	1.0077	1.0075	1.0074	1.0072	1.0070	1.0068	1.0067	1.0065	1.0063	1.0060	1.0058	1.0056
1.6	1.0108	1.0107	1.0106	1.0104	1.0101	1.0097	1.0097	1.0095	1.0093	1.0090	1.0088	1.0086	1.0085	1.0083	1.0081	1.0080	1.0078	1.0076	1.0075	1.0073	1.0071	1.0069	1.0066	1.0064	1.0062	1.0059
1.7	1.0114	1.0114	1.0113	1.0110	1.0108	1.0104	1.0103	1.0101	1.0099	1.0096	1.0094	1.0092	1.0091	1.0089	1.0087	1.0086	1.0084	1.0082	1.0080	1.0078	1.0076	1.0074	1.0071	1.0069	1.0066	1.0064
1.8	1.0121	1.0120	1.0120	1.0117	1.0114	1.0110	1.0108	1.0106	1.0104	1.0102	1.0100	1.0097	1.0096	1.0094	1.0092	1.0091	1.0089	1.0087	1.0084	1.0082	1.0080	1.0078	1.0075	1.0073	1.0070	1.0067
1.9	1.0128	1.0127	1.0126	1.0123	1.0120	1.0116	1.0115	1.0112	1.0110	1.0107	1.0104	1.0103	1.0101	1.0099	1.0097	1.0095	1.0093	1.0091	1.0089	1.0087	1.0084	1.0082	1.0079	1.0077	1.0074	1.0071
2.0	1.0134	1.0133	1.0132	1.0129	1.0126	1.0122	1.0121	1.0118	1.0116	1.0113	1.0110	1.0108	1.0106	1.0104	1.0102	1.0100	1.0098	1.0096	1.0094	1.0092	1.0089	1.0087	1.0084	1.0081	1.0078	1.0075
2.1	1.0140	1.0140	1.0139	1.0136	1.0133	1.0129	1.0127	1.0124	1.0122	1.0119	1.0115	1.0114	1.0111	1.0110	1.0108	1.0105	1.0103	1.0101	1.0099	1.0096	1.0094	1.0091	1.0088	1.0085	1.0082	1.0079
2.2	1.0147	1.0147	1.0146	1.0142	1.0139	1.0135	1.0133	1.0130	1.0128	1.0125	1.0121	1.0120	1.0118	1.0116	1.0114	1.0111	1.0109	1.0107	1.0104	1.0101	1.0098	1.0095	1.0094	1.0089	1.0086	1.0083
2.3	1.0154	1.0154	1.0153	1.0149	1.0146	1.0141	1.0139	1.0136	1.0133	1.0130	1.0127	1.0125	1.0123	1.0121	1.0119	1.0116	1.0114	1.0111	1.0109	1.0106	1.0103	1.0100	1.0097	1.0093	1.0090	1.0086
2.4	1.0160	1.0160	1.0159	1.0154	1.0151	1.0146	1.0144	1.0141	1.0138	1.0135	1.0133	1.0130	1.0128	1.0126	1.0124	1.0121	1.0119	1.0116	1.0114	1.0111	1.0108	1.0105	1.0102	1.0098	1.0095	1.0091
2.5	1.0167	1.0167	1.0166	1.0162	1.0158	1.0153	1.0150	1.0148	1.0145	1.0141	1.0137	1.0135	1.0133	1.0131	1.0128	1.0126	1.0123	1.0120	1.0118	1.0115	1.0112	1.0109	1.0106	1.0102	1.0098	1.0094
2.6	1.0174	1.0173	1.0172	1.0168	1.0164	1.0159	1.0156	1.0154	1.0151	1.0147	1.0143	1.0141	1.0139	1.0136	1.0134	1.0131	1.0128	1.0125	1.0123	1.0120	1.0116	1.0113	1.0110	1.0106	1.0102	1.0099
2.7	1.0183	1.0182	1.0181	1.0176	1.0172	1.0167	1.0164	1.0161	1.0158	1.0154	1.0150	1.0148	1.0146	1.0143	1.0141	1.0138	1.0135	1.0132	1.0129	1.0126	1.0123	1.0119	1.0115	1.0111	1.0107	1.0103
2.8	1.0187	1.0186	1.0185	1.0180	1.0176	1.0171	1.0168	1.0165	1.0162	1.0158	1.0154	1.0152	1.0149	1.0147	1.0144	1.0141	1.0139	1.0136	1.0132	1.0129	1.0126	1.0122	1.0118	1.0114	1.0110	1.0106
2.9	1.0194	1.0194	1.0192	1.0187	1.0183	1.0177	1.0175	1.0172	1.0168	1.0164	1.0160	1.0157	1.0155	1.0152	1.0150	1.0147	1.0144	1.0141	1.0137	1.0134	1.0130	1.0127	1.0123	1.0119	1.0114	1.0110
3.0	1.0200	1.0200	1.0198	1.0193	1.0189	1.0183	1.0180	1.0177	1.0173	1.0169	1.0165	1.0162	1.0160	1.0157	1.0155	1.0152	1.0149	1.0146	1.0142	1.0139	1.0135	1.0131	1.0127	1.0123	1.0119	1.0114
3.1	1.0207	1.0206	1.0205	1.0200	1.0195	1.0189	1.0186	1.0183	1.0179	1.0175	1.0171	1.0168	1.0166	1.0163	1.0160	1.0157	1.0153	1.0150	1.0147	1.0143	1.0139	1.0135	1.0131	1.0127	1.0123	1.0118
3.2	1.0213	1.0213	1.0211	1.0206	1.0201	1.0195	1.0192	1.0189	1.0185	1.0180	1.0176	1.0173	1.0171	1.0168	1.0165	1.0162	1.0158	1.0155	1.0152	1.0148	1.0144	1.0140	1.0136	1.0131	1.0127	1.0122
3.3	1.0220	1.0220	1.0218	1.0213	1.0208	1.0202	1.0199	1.0195	1.0191	1.0186	1.0181	1.0178	1.0176	1.0173	1.0170	1.0166	1.0163	1.0159	1.0156	1.0152	1.0148	1.0144	1.0139	1.0135	1.0130	1.0125
3.4	1.0227	1.0227	1.0225	1.0219	1.0214	1.0208	1.0205	1.0201	1.0197	1.0192	1.0187	1.0184	1.0182	1.0179	1.0175	1.0172	1.0169	1.0165	1.0161	1.0157	1.0153	1.0149	1.0144	1.0139	1.0135	1.0129
3.5	1.0233	1.0233	1.0231	1.0225	1.0220	1.0214	1.0210	1.0207	1.0202	1.0198	1.0192	1.0190	1.0187	1.0183	1.0180	1.0177	1.0173	1.0169	1.0165	1.0161	1.0157	1.0153	1.0148	1.0143	1.0139	1.0133
3.6	1.0240	1.0239	1.0237	1.0232	1.0227	1.0220	1.0216	1.0212	1.0208	1.0203	1.0198	1.0195	1.0192	1.0188	1.0185	1.0182	1.0178	1.0174	1.0170	1.0166	1.0162	1.0158	1.0153	1.0148	1.0143	1.0138
3.7	1.0246	1.0246	1.0244	1.0238	1.0232	1.0225	1.0221	1.0217	1.0213	1.0208	1.0203	1.0200	1.0197	1.0193	1.0190	1.0187	1.0183	1.0179	1.0175	1.0171	1.0166	1.0162	1.0157	1.0152	1.0146	1.0141
3.8	1.0252	1.0252	1.0250	1.0244	1.0238	1.0231	1.0227	1.0223	1.0219	1.0214	1.0209	1.0206	1.0203	1.0199	1.0196	1.0192	1.0189	1.0185	1.0180	1.0176	1.0171	1.0167	1.0162	1.0156	1.0151	1.0145
3.9	1.0259	1.0259	1.0257	1.0250	1.0245	1.0237	1.0234	1.0229	1.0225	1.0220	1.0214	1.0211	1.0208	1.0205	1.0201	1.0197	1.0193	1.0189	1.0185	1.0180	1.0176	1.0171	1.0166	1.0160	1.0155	1.0149
4.0	1.0265	1.0265	1.0263	1.0256	1.0251	1.0243	1.0240	1.0235	1.0231	1.0225	1.0220	1.0217	1.0213	1.0210	1.0206	1.0202	1.0198	1.0194	1.0190	1.0185	1.0180	1.0175	1.0170	1.0164	1.0159	1.0153

NOTE: Above tables are for use on natural gas and are based on ratio of specific heats equal to 1.30.

TABLE 10-A Y_m EXPANSION FACTORS — FLANGE TAPS

Static Pressure, Mean of Upstream and Downstream

Line Size	ORIFICE SIZES																										
2"	½" ⅝" ¾"	⅞" 1" 1½"																									
3"	½" ⅝" ¾"	⅞" 1" 1¼"	1⅜"	1½"		1⅝"		1¾"		1⅞"				2"				2⅛"				2¼"					
4"	½" ⅝" 1"	1¼" 1⅜" 1½"	1¾"	2"	2⅛"		2¼"	2⅜"			2½"			2⅝"			2¾"			2⅞"				3"		
6"	⅞" 1" 1½"	2"	2⅛" 2½"	2⅝" 2⅞"	3"	3⅛"	3¼"	3⅜"	3½"	3⅝"		3¾"		3⅞"		4"			4¼"				4½"		
8"	1⅛" 2"	2⅛" 2¾"	2⅞" 3⅜"	3½" 3¾"	3⅞" 4"	4¼"		4½"	4¾"		5"			5¼"			5½"			5¾"			6"		
10"	1⅛" 1½"	1⅝" 2½"	2⅝" 3½"	3⅝" 4¼"	4½" 4¾"	5"	5¼"	5½"	5¾"		6"		6¼"		6½"			6¾"		7"		7¼"		7½"		
12"	1⅛" 1¾"	1⅞" 3"	3⅛" 4"	4¼" 5"	5¼" 5½"	5¾" 6"	6¼"	6½"	6¾"	7"	7¼"		7½"		7¾"		8"		8¼"		8½"		8¾"		9"		
15¼"	⅛" 2¼"	2½" 3¾"	3⅞" 5¼"	5½" 6¼"	6½" 7¼"	7½" 7¾"	8"	8¼"	8½"	8¾"	9"	9¼"	9½"		9¾"		10"	10¼"		10½"	10¾"		11"		11¼"		

$\frac{h_w}{p_m}$ Ratio $\beta = \frac{D_2}{D_1}$, Ratio

Ratio	.1	.2	.3	.4	.45	.50	.52	.54	.56	.58	.60	.61	.62	.63	.64	.65	.66	.67	.68	.69	.70	.71	.72	.73	.74	.75
0.1	.9998	.9998	.9998	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9996	.9996	.9996	.9996	.9996	.9996	.9996	.9996	.9996	.9995	.9995	.9995	.9995	.9995	.9995	.9995
0.2	.9995	.9995	.9995	.9995	.9994	.9994	.9994	.9994	.9993	.9993	.9993	.9993	.9992	.9992	.9992	.9992	.9992	.9991	.9991	.9991	.9991	.9990	.9990	.9990	.9989	.9989
0.3	.9993	.9993	.9993	.9992	.9992	.9991	.9991	.9990	.9990	.9990	.9989	.9989	.9989	.9988	.9988	.9988	.9987	.9987	.9987	.9986	.9986	.9986	.9985	.9985	.9984	.9984
0.4	.9991	.9991	.9990	.9990	.9989	.9988	.9988	.9987	.9987	.9986	.9986	.9985	.9985	.9984	.9984	.9984	.9983	.9983	.9982	.9982	.9981	.9981	.9980	.9980	.9979	.9978
0.5	.9988	.9988	.9988	.9987	.9986	.9985	.9985	.9984	.9983	.9983	.9982	.9981	.9981	.9981	.9980	.9980	.9979	.9978	.9978	.9977	.9977	.9976	.9975	.9974	.9974	.9973
0.6	.9986	.9986	.9985	.9984	.9984	.9982	.9982	.9981	.9980	.9979	.9978	.9978	.9977	.9977	.9976	.9975	.9975	.9974	.9973	.9973	.9972	.9971	.9970	.9969	.9968	.9967
0.7	.9984	.9984	.9983	.9982	.9981	.9979	.9979	.9978	.9977	.9976	.9975	.9974	.9973	.9973	.9972	.9971	.9971	.9970	.9969	.9968	.9967	.9966	.9965	.9964	.9963	.9962
0.8	.9981	.9981	.9981	.9979	.9978	.9976	.9976	.9975	.9974	.9972	.9971	.9970	.9970	.9969	.9968	.9967	.9967	.9965	.9965	.9964	.9963	.9962	.9961	.9960	.9959	.9957
0.9	.9979	.9979	.9978	.9977	.9975	.9973	.9973	.9972	.9971	.9969	.9968	.9967	.9967	.9966	.9965	.9964	.9963	.9962	.9961	.9960	.9959	.9957	.9956	.9955	.9953	.9952
1.0	.9977	.9977	.9976	.9975	.9973	.9971	.9970	.9969	.9968	.9967	.9965	.9964	.9963	.9962	.9961	.9960	.9959	.9958	.9957	.9955	.9954	.9953	.9951	.9950	.9948	.9947
1.1	.9975	.9974	.9974	.9972	.9971	.9968	.9967	.9966	.9965	.9963	.9961	.9960	.9959	.9958	.9957	.9956	.9955	.9953	.9952	.9951	.9949	.9948	.9946	.9945	.9943	.9941
1.2	.9973	.9973	.9972	.9970	.9968	.9966	.9964	.9963	.9961	.9960	.9958	.9957	.9955	.9954	.9953	.9952	.9951	.9949	.9948	.9946	.9945	.9943	.9941	.9940	.9938	.9936
1.3	.9971	.9970	.9970	.9967	.9965	.9963	.9961	.9960	.9958	.9956	.9954	.9953	.9952	.9951	.9949	.9948	.9946	.9945	.9943	.9942	.9940	.9938	.9936	.9934	.9933	.9931
1.4	.9968	.9968	.9967	.9965	.9963	.9960	.9958	.9957	.9955	.9953	.9951	.9949	.9948	.9947	.9945	.9944	.9942	.9941	.9939	.9938	.9936	.9934	.9932	.9930	.9928	.9926
1.5	.9966	.9966	.9965	.9962	.9960	.9957	.9955	.9954	.9952	.9950	.9948	.9946	.9945	.9944	.9942	.9941	.9939	.9937	.9935	.9933	.9932	.9929	.9927	.9925	.9923	.9920
1.6	.9964	.9964	.9962	.9960	.9957	.9954	.9952	.9950	.9948	.9946	.9944	.9943	.9941	.9940	.9938	.9937	.9935	.9933	.9931	.9929	.9927	.9925	.9922	.9920	.9918	.9915
1.7	.9962	.9962	.9960	.9958	.9955	.9952	.9950	.9948	.9946	.9943	.9941	.9939	.9938	.9936	.9934	.9933	.9931	.9929	.9927	.9925	.9923	.9921	.9918	.9916	.9913	.9910
1.8	.9959	.9959	.9958	.9955	.9953	.9949	.9947	.9945	.9943	.9940	.9937	.9936	.9934	.9932	.9930	.9928	.9927	.9925	.9923	.9920	.9918	.9916	.9913	.9911	.9908	.9905
1.9	.9957	.9957	.9956	.9953	.9950	.9948	.9944	.9942	.9940	.9937	.9934	.9933	.9931	.9929	.9927	.9925	.9923	.9921	.9919	.9916	.9914	.9911	.9908	.9906	.9903	.9900
2.0	.9955	.9954	.9953	.9950	.9946	.9942	.9940	.9938	.9935	.9932	.9929	.9927	.9925	.9923	.9921	.9919	.9917	.9915	.9912	.9910	.9907	.9904	.9901	.9899	.9896	.9892
2.1	.9953	.9953	.9952	.9948	.9945	.9940	.9938	.9936	.9933	.9930	.9927	.9925	.9923	.9921	.9919	.9917	.9915	.9913	.9910	.9908	.9905	.9902	.9899	.9896	.9893	.9890
2.2	.9951	.9951	.9950	.0047	.9943	.9938	.9936	.9934	.9931	.9927	.9924	.9922	.9920	.9918	.9916	.9913	.9911	.9908	.9906	.9903	.9900	.9897	.9894	.9892	.9888	.9884
2.3	.9949	.9949	.9947	.9944	.9940	.9936	.9933	.9931	.9928	.9924	.9921	.9919	.9917	.9915	.9913	.9910	.9908	.9905	.9902	.9900	.9897	.9894	.9891	.9887	.9884	.9880
2.4	.9947	.9947	.9945	.9941	.9938	.9933	.9930	.9927	.9924	.9921	.9917	.9915	.9913	.9911	.9909	.9906	.9904	.9901	.9898	.9895	.9892	.9889	.9886	.9882	.9878	.9875
2.5	.9945	.9944	.9943	.9938	.9935	.9930	.9927	.9924	.9921	.9918	.9914	.9912	.9909	.9907	.9905	.9902	.9900	.9897	.9894	.9891	.9888	.9885	.9881	.9878	.9874	.9870
2.6	.9943	.9942	.9941	.9936	.9933	.9928	.9925	.9922	.9919	.9915	.9911	.9909	.9907	.9904	.9902	.9899	.9896	.9893	.9890	.9887	.9884	.9880	.9876	.9873	.9869	.9865
2.7	.9941	.9941	.9939	.9934	.9930	.9925	.9922	.9919	.9916	.9912	.9907	.9905	.9903	.9900	.9898	.9895	.9892	.9889	.9886	.9883	.9880	.9876	.9872	.9869	.9864	.9860
2.8	.9939	.9938	.9937	.9932	.9928	.9922	.9919	.9916	.9913	.9909	.9904	.9902	.9900	.9897	.9895	.9892	.9889	.9886	.9882	.9879	.9875	.9871	.9867	.9864	.9859	.9855
2.9	.9937	.9936	.9934	.9929	.9925	.9919	.9916	.9913	.9909	.9905	.9901	.9899	.9896	.9893	.9891	.9888	.9885	.9882	.9878	.9874	.9871	.9867	.9863	.9859	.9855	.9850
3.0	.9935	.9934	.9932	.9927	.9923	.9917	.9914	.9911	.9907	.9903	.9898	.9895	.9892	.9890	.9887	.9884	.9881	.9877	.9874	.9870	.9867	.9863	.9859	.9854	.9850	.9845
3.1	.9932	.9932	.9930	.9925	.9920	.9914	.9911	.9908	.9904	.9900	.9895	.9892	.9890	.9887	.9884	.9881	.9877	.9874	.9870	.9867	.9863	.9859	.9854	.9850	.9845	.9840
3.2	.9931	.9931	.9929	.9923	.9919	.9912	.9909	.9905	.9901	.9897	.9892	.9889	.9886	.9883	.9880	.9877	.9873	.9870	.9866	.9862	.9858	.9854	.9850	.9845	.9840	.9835
3.3	.9929	.9928	.9926	.9921	.9916	.9909	.9906	.9902	.9898	.9894	.9889	.9886	.9883	.9880	.9877	.9873	.9870	.9866	.9863	.9859	.9854	.9850	.9845	.9841	.9836	.9831
3.4	.9927	.9926	.9924	.9918	.9913	.9907	.9903	.9899	.9895	.9890	.9885	.9882	.9789	.9876	.9873	.9859	.9866	.9862	.9858	.9854	.9850	.9845	.9841	.9836	.9831	.9825
3.5	.9925	.9924	.9922	.9916	.9911	.9905	.9901	.9897	.9893	.9888	.9883	.9880	.9877	.9873	.9870	.9866	.9863	.9859	.9855	.9850	.9846	.9841	.9837	.9832	.9826	.9821
3.6	.9923	.9923	.9920	.9914	.9909	.9902	.9898	.9894	.9890	.9885	.9878	.9876	.9873	.9869	.9866	.9862	.9859	.9855	.9851	.9846	.9842	.9837	.9833	.9827	.9822	.9816
3.7	.9921	.9920	.9918	.9912	.9907	.9899	.9895	.9891	.9887	.9882	.9876	.9873	.9870	.9866	.9863	.9859	.9855	.9851	.9847	.9842	.9838	.9833	.9828	.9822	.9817	.9811
3.8	.9919	.9918	.9916	.9910	.9905	.9897	.9893	.9889	.9884	.9879	.9873	.9870	.9866	.9863	.9859	.9855	.9851	.9847	.9843	.9838	.9834	.9829	.9824	.9818	.9813	.9807
3.9	.9918	.9917	.9915	.9908	.9902	.9894	.9890	.9886	.9881	.9876	.9870	.9867	.9863	.9860	.9856	.9852	.9848	.9844	.9839	.9835	.9830	.9825	.9820	.9814	.9808	.9802
4.0	.9916	.9915	.9913	.9906	.9900	.9892	.9888	.9884	.9879	.9873	.9867	.9864	.9861	.9857	.9853	.9849	.9845	.9840	.9836	.9831	.9826	.9820	.9815	.9809	.9803	.9797

NOTE: Above tables are for use on natural gas and are based on ratio of specific heats equal to 1.30.

TABLE 13
F_{pb}

FACTORS TO CHANGE FROM A PRESSURE BASE OF 14.4 POUNDS PER SQUARE INCH ABSOLUTE TO SOME OTHER CONTRACT PRESSURE BASE

CONTRACT PRESSURE BASE			F_{pb}
Above 14.4		Absolute	Correction
Oz.	Lb.	Lb.	Factors
2	.125	14.525	.9914
4	.250	14.65	.9829
(30" Hg., Absolute)		14.73	.9776
6	.375	14.775	.9746
8	.500	14.90	.9664
10	.625	15.025	.9584
12	.750	15.15	.9505
14	.875	15.275	.9427
16	1.000	15.40	.9351
18	1.125	15.525	.9275
20	1.250	15.65	.9201
22	1.375	15.775	.9128
24	1.500	15.90	.9057
26	1.625	16.025	.8986
28	1.750	16.15	.8916
30	1.875	16.275	.8848
32	2.000	16.40	.8780
34	2.125	16.525	.8714
36	2.250	16.65	.8649
38	2.375	16.775	.8584
40	2.500	16.90	.8521
42	2.625	17.025	.8458
44	2.750	17.15	.8397
46	2.875	17.275	.8336
48	3.000	17.40	.8276

TABLE 14
F_{tb}

FACTORS TO CHANGE FROM A TEMPERATURE BASE OF 60° F. TO CONTRACT TEMPERATURE BASE

Temperature Degrees F.	F_{tb}	Temperature Degrees F.	F_{tb}
40	.9615	65	1.0096
41	.9635	66	1.0115
42	.9654	67	1.0135
43	.9673	68	1.0154
44	.9692	69	1.0173
45	.9712	70	1.0192
46	.9731	71	1.0212
47	.9750	72	1.0231
48	.9769	73	1.0250
49	.9788	74	1.0269
50	.9808	75	1.0288
51	.9827	76	1.0308
52	.9846	77	1.0327
53	.9865	78	1.0346
54	.9885	79	1.0365
55	.9904	80	1.0385
56	.9923	81	1.0404
57	.9942	82	1.0423
58	.9962	83	1.0442
59	.9981	84	1.0462
60	1.0000	85	1.0481
61	1.0019	86	1.0500
62	1.0038	87	1.0519
63	1.0058	88	1.0538
64	1.0077	89	1.0558
		90	1.0577

TABLE 15
F_{tf}

FACTOR TO CHANGE FROM FLOWING TEMPERATURE OF 60° FAHRENHEIT TO ACTUAL FLOWING TEMPERATURE

Temp. °F.	F_{tf}	Temp. °F.	F_{tf}	Temp. °F.	F_{tf}
1	1.0621	51	1.0088	101	.9628
2	1.0609	52	1.0078	102	.9619
3	1.0598	53	1.0068	103	.9610
4	1.0586	54	1.0058	104	.9602
5	1.0575	55	1.0048	105	.9594
6	1.0564	56	1.0039	106	.9585
7	1.0552	57	1.0029	107	.9577
8	1.0541	58	1.0019	108	.9568
9	1.0530	59	1.0010	109	.9560
10	1.0518	60	1.0000	110	.9551
11	1.0507	61	.9990	111	.9543
12	1.0496	62	.9981	112	.9535
13	1.0485	63	.9971	113	.9526
14	1.0474	64	.9962	114	.9518
15	1.0463	65	.9952	115	.9510
16	1.0452	66	.9943	116	.9501
17	1.0441	67	.9938	117	.9493
18	1.0430	68	.9924	118	.9485
19	1.0419	69	.9915	119	.9477
20	1.0408	70	.9905	120	.9469
21	1.0398	71	.9896	121	.9460
22	1.0387	72	.9887	122	.9452
23	1.0376	73	.9877	123	.9444
24	1.0365	74	.9868	124	.9436
25	1.0355	75	.9859	125	.9428
26	1.0344	76	.9850	126	.9420
27	1.0333	77	.9840	127	.9412
28	1.0323	78	.9831	128	.9404
29	1.0312	79	.9822	129	.9396
30	1.0302	80	.9813	130	.9388
31	1.0291	81	.9804	131	.9380
32	1.0281	82	.9795	132	.9372
33	1.0270	83	.9786	133	.9364
34	1.0260	84	.9777	134	.9356
35	1.0249	85	.9768	135	.9349
36	1.0239	86	.9759	136	.9341
37	1.0229	87	.9750	137	.9333
38	1.0218	88	.9741	138	.9325
39	1.0208	89	.9732	139	.9317
40	1.0198	90	.9723	140	.9309
41	1.0188	91	.9715	141	.9302
42	1.0178	92	.9706	142	.9294
43	1.0168	93	.9697	143	.9286
44	1.0158	94	.9688	144	.9279
45	1.0147	95	.9680	145	.9271
46	1.0137	96	.9671	146	.9263
47	1.0127	97	.9662	147	.9256
48	1.0117	98	.9653	148	.9248
49	1.0108	99	.9645	149	.9240
50	1.0098	100	.9636	150	.9233

TABLE 16
F_g

FACTORS TO ADJUST FOR SPECIFIC GRAVITY

Flowing Gravity G	F_g	Flowing Gravity G	F_g	Flowing Gravity G	F_g
.500	1.4142	.675	1.2172	.850	1.0847
.505	1.4072	.680	1.2127	.855	1.0815
.510	1.4003	.685	1.2082	.860	1.0783
.515	1.3935	.690	1.2039	.865	1.0752
.520	1.3868	.695	1.1995	.870	1.0721
.525	1.3801	.700	1.1952	.875	1.0690
.530	1.3736	.705	1.1910	.880	1.0660
.535	1.3672	.710	1.1868	.885	1.0630
.540	1.3608	.715	1.1826	.890	1.0600
.545	1.3546	.720	1.1785	.895	1.0570
.550	1.3484	.725	1.1744	.900	1.0541
.555	1.3423	.730	1.1704	.905	1.0512
.560	1.3363	.735	1.1664	.910	1.0483
.565	1.3304	.740	1.1625	.915	1.0454
.570	1.3245	.745	1.1586	.920	1.0426
.575	1.3188	.750	1.1547	.925	1.0398
.580	1.3131	.755	1.1509	.930	1.0370
.585	1.3074	.760	1.1471	.935	1.0342
.590	1.3019	.765	1.1433	.940	1.0314
.595	1.2964	.770	1.1396	.945	1.0287
.600	1.2910	.775	1.1359	.950	1.0260
.605	1.2856	.780	1.1323	.955	1.0233
.610	1.2804	.785	1.1287	.960	1.0206
.615	1.2752	.790	1.1251	.965	1.0180
.620	1.2700	.795	1.1215	.970	1.0153
.625	1.2649	.800	1.1180	.975	1.0127
.630	1.2599	.805	1.1146	.980	1.0102
.635	1.2549	.810	1.1111	.985	1.0076
.640	1.2500	.815	1.1077	.990	1.0050
.645	1.2451	.820	1.1043	.995	1.0025
.650	1.2403	.825	1.1010	1.000	1.0000
.655	1.2356	.830	1.0976		
.660	1.2309	.835	1.0944		
.665	1.2263	.840	1.0911		
.670	1.2217	.845	1.0879		

TABLE 17
F_{pv}

SUPERCOMPRESSIBILITY FACTORS

Supercompressibility Ratio N	Supercompressibility Factor F_{pv}	Supercompressibility Ratio N	Supercompressibility Factor F_{pv}
.000	1.0000	.070	1.0344
.002	1.0010	.072	1.0354
.004	1.0020	.074	1.0363
.006	1.0030	.076	1.0373
.008	1.0040	.078	1.0383
.010	1.0050	.080	1.0392
.012	1.0060	.082	1.0402
.014	1.0070	.084	1.0412
.016	1.0080	.086	1.0421
.018	1.0090	.088	1.0431
.020	1.0100	.090	1.0440
.022	1.0109	.092	1.0450
.024	1.0119	.094	1.0459
.026	1.0129	.096	1.0469
.028	1.0139	.098	1.0479
.030	1.0149	.100	1.0488
.032	1.0159	.102	1.0498
.034	1.0169	.104	1.0507
.036	1.0178	.106	1.0517
.038	1.0188	.108	1.0526
.040	1.0198	.110	1.0536
.042	1.0208	.112	1.0545
.044	1.0218	.114	1.0555
.046	1.0227	.116	1.0564
.048	1.0237	.118	1.0574
.050	1.0247	.120	1.0583
.052	1.0257	.122	1.0592
.054	1.0266	.124	1.0602
.056	1.0276	.126	1.0611
.058	1.0286	.128	1.0621
.060	1.0296	.130	1.0630
.062	1.0305	.132	1.0640
.064	1.0315	.134	1.0649
.066	1.0325	.136	1.0658
.068	1.0334	.138	1.0668
		.140	1.0677

FUEL CONSUMPTION OF GAS ENGINES

The amount of gas required per hp hour is dependent upon the efficiency of the engine and the percentage of full load at which it is operating. As the hp output of the engine decreases, the fuel consumption per hp hour increases. For estimating purposes, the following figures may safely be used.

Per Cent of Full Load	*Btu per HP Hr*
100	10,200
75	11,200
50	14,500
25	20,600

Inasmuch as most engines operate between 75 and 100 per cent of full load, the accepted practice is to figure 11,200 Btu per hp hour.

BTU PER BRAKE HORSEPOWER HOUR

Per Cent Load	*Small Bore below 7"*	*Large Bore above 7"*
100%	10,200	9,700
90%	10,300	9,900
80%	10,800	10,200
70%	11,300	10,900
60%	13,000	11,800
50%	14,500	13,000
40%	16,500	14,800
30%	19,000	17,000
20%	23,000	20,500

The above figures do not include the power required to operate the auxiliaries such as: cooling water pump, fan charging generator, etc.

The heat to be dissipated in a gas engine is approximately as follows:

Cooling water 3000 Btu per BHP hour or 50 Btu per minute per BHP.
Exhaust 3500 Btu per BHP hour or 59 Btu per minute per BHP.

The formula for figuring the quantity of cooling water required is as follows:

$$GPM = \frac{BHP \times Btu}{T \times 8.33}$$

where
GPM = Gallons per minute of cooling water
BHP = Brake horse power load on engine
Btu = Heat to be dissipated—Btu per minute
T = Difference in cooling water temperature in and out.

The heat balance of a natural gas engine at full load is approximately as follows:

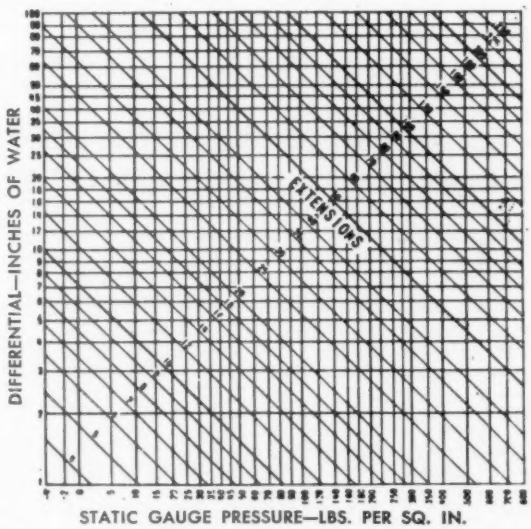
Brake horse power	25%
*Friction	7%
Cooling Water	30%
Exhaust	35%
Radiation	3%

* The heat generated in friction is dissipated in the cooling water and radiation.

AGA Gas Engine Handbook.

METHODS OF DETERMINING APPROXIMATE HOURLY FLOW THROUGH AN ORIFICE METER

(1) Locate differential on left margin.
(2) Trace to right to perpendicular line representing static gauge pressure on bottom scale.
(3) Read extension factor from diagonal lines.
(4) Hourly flow in cu. ft. = extension factor × orifice flow constants taken from tables No. XIV or XV.



Example: Assume an orifice meter with a 2″ orifice in a 4″ pipe run, having a differential of 40″ and a static pressure of 200 lbs., flange taps being used.
Then: Extension = 95
Orifice flow constant = 1070
Hourly flow = 95 × 1070 = 102,000 Cu. Ft.

APPROXIMATE HOURLY ORIFICE FLOW CONSTANTS—FLANGE TAPS

Based on .65 specific gravity gas at average atmospheric pressure and temperature. TABLE XIV

Orifice Diameter Inches	Pipe Sizes 2″ Std. (2.067)	3″ Std. (3.068)	4″ Std. (4.026)	6″ Std. (6.065)	8″ Std. (8.071)	10″ Std. (10.136)	12″ Std. (12.090)
.25	16	16	16				
.375	36	36	36				
.50	64	64	64	64			
.625	101	100	99	99			
.75	146	144	143	143			
.875	201	197	196	195	195		
1.00	267	258	256	255	254		
1.125	345	329	325	323	322	322	
1.25	438	409	403	399	398	397	397
1.375	550	499	489	484	482	481	481
1.50	688	600	585	577	574	573	572
1.625		714	690	678	675	673	672
1.75		842	805	788	783	781	780
1.875		986	931	906	900	898	896
2.00		1150	1070	1030	1030	1020	1020
2.125		1340	1220	1170	1160	1160	1150
2.25		1550	1380	1320	1300	1300	1290
2.375			1560	1470	1450	1450	1440
2.50			1760	1630	1610	1600	1600
2.625			1980	1810	1780	1770	1760
2.75			2220	2000	1960	1940	1940
2.875			2480	2190	2140	2130	2120
3.00			2790	2400	2340	2320	2310
3.125				2620	2540	2520	2510
3.25				2860	2760	2730	2710
3.375				3100	2980	2940	2930
3.50				3370	3220	3170	3150
3.625				3650	3460	3410	3390
3.75				3950	3720	3650	3630
3.875				4270	3990	3910	3880
4.00				4600	4270	4170	4130
4.25				5350	4860	4730	4680
4.50				6220	5520	5330	5260
4.75					6230	5970	5880
5.00					7020	6660	6540
5.25					7880	7400	7240
5.50					8820	8190	7980
5.75					9870	9040	8760
6.00					11000	9960	9600
6.25	Note: The above Flow Constants					10900	10500
6.50	are only approximate values and					12000	11400
6.75	should not be used in Commercial					13100	12400
7.00	Gas Measurement Computations.					14400	13500
7.25						15700	14600
7.50						17200	15800
7.75							17000
8.00							18400
8.25							19800
8.50							21400
8.75							23000
9.00							24800

APPROXIMATE HOURLY ORIFICE FLOW CONSTANTS—PIPE TAPS

Based on .65 specific gravity gas at average atmospheric pressure and temperature. TABLE XV

Orifice Diameter Inches	Pipe Sizes 2″ Std. (2.067)	3″ Std. (3.068)	4″ Std. (4.026)	6″ Std. (6.065)	8″ Std. (8.071)	10″ Std. (10.136)	12″ Std. (12.090)
.25	16	16	16				
.375	37	36	36				
.50	67	65	65	64			
.625	107	103	101	100			
.75	159	150	147	145			
.875	225	207	202	198	197		
1.00	309	276	266	259	257		
1.125	416	357	341	330	326	325	
1.25	556	453	428	410	404	402	400
1.375	741	566	526	499	491	487	485
1.50		698	637	598	586	581	578
1.625		854	764	708	691	683	679
1.75		1040	906	829	805	795	789
1.875		1260	1070	961	929	915	908
2.00		1530	1250	1110	1060	1050	1040
2.125		1860	1460	1260	1210	1180	1170
2.25			1690	1430	1360	1330	1320
2.375			1960	1620	1530	1490	1470
2.50			2270	1820	1710	1660	1640
2.625			2630	2040	1900	1840	1811
2.75			3050	2270	2100	2030	2000
2.875				2530	2320	2230	2190
3.00				2810	2550	2440	2390
3.125				3110	2790	2670	2610
3.25				3440	3050	2900	2830
3.375				3800	3330	3150	3070
3.50				4190	3620	3410	3320
3.625				4620	3930	3690	3570
3.75				5090	4260	3980	3840
3.875				5610	4620	4280	4130
4.00				6190	4990	4600	4420
4.25					5820	5280	5050
4.50					6760	6030	5730
4.75					7840	6860	6470
5.00					9070	7780	7280
5.25					10500	8800	8150
5.50					12200	9920	9100
5.75						11200	10100
6.00						12600	11200
6.25	Note: The above Flow Constants					14100	12500
6.50	are only approximate values and					15900	13800
6.75	should not be used in Commercial					17800	15200
7.00	Gas Measurement Computations.					20000	16800
7.25							18500
7.50							20400
7.75							22500
8.00							24800
8.25							27400

From Report No. 2, Practical Methods Committee, Appalachian Gas Measurement Short Course, School of Mines, West Virginia University, 1940.

FACTORS TO ADJUST ORIFICE METER DELIVERIES FOR SUPERCOMPRESSIBILITY—AVERAGE CONDITIONS

Gauge Press. # /sq."	0	1	2	3	4	5	6	7	8	9
0	1.0000	1.0001	1.0002	1.0003	1.0005	1.0006	1.0007	1.0008	1.0009	1.0010
10	1.0011	1.0012	1.0014	1.0015	1.0016	1.0017	1.0018	1.0019	1.0020	1.0022
20	1.0023	1.0024	1.0025	1.0026	1.0027	1.0028	1.0029	1.0031	1.0032	1.0033
30	1.0034	1.0035	1.0036	1.0037	1.0039	1.0040	1.0041	1.0042	1.0043	1.0044
40	1.0045	1.0047	1.0048	1.0049	1.0050	1.0051	1.0052	1.0053	1.0054	1.0056
50	1.0057	1.0058	1.0059	1.0060	1.0061	1.0062	1.0064	1.0065	1.0066	1.0067
60	1.0068	1.0069	1.0070	1.0072	1.0073	1.0074	1.0075	1.0076	1.0077	1.0078
70	1.0080	1.0081	1.0082	1.0083	1.0084	1.0085	1.0086	1.0088	1.0089	1.0090
80	1.0091	1.0092	1.0093	1.0095	1.0096	1.0097	1.0098	1.0099	1.0100	1.0101
90	1.0102	1.0104	1.0105	1.0106	1.0107	1.0108	1.0109	1.0111	1.0112	1.0113
100	1.0114	1.0115	1.0116	1.0117	1.0118	1.0119	1.0121	1.0122	1.0123	1.0124
110	1.0125	1.0126	1.0127	1.0128	1.0130	1.0131	1.0132	1.0133	1.0134	1.0135
120	1.0136	1.0137	1.0139	1.0140	1.0141	1.0142	1.0143	1.0141	1.0145	1.0146
130	1.0148	1.0149	1.0150	1.0151	1.0152	1.0153	1.0154	1.0156	1.0157	1.0158
140	1.0159	1.0160	1.0161	1.0162	1.0163	1.0164	1.0166	1.0167	1.0168	1.0169
150	1.0170	1.0171	1.0172	1.0174	1.0175	1.0176	1.0177	1.0178	1.0179	1.0180
160	1.0181	1.0182	1.0184	1.0185	1.0186	1.0187	1.0188	1.0189	1.0190	1.0191
170	1.0193	1.0194	1.0195	1.0196	1.0197	1.0198	1.0199	1.0200	1.0202	1.0203
180	1.0204	1.0205	1.0206	1.0207	1.0208	1.0209	1.0210	1.0212	1.0213	1.0214
190	1.0215	1.0216	1.0217	1.0218	1.0219	1.0220	1.0222	1.0223	1.0224	1.0225
200	1.0226	1.0227	1.0228	1.0229	1.0230	1.0232	1.0233	1.0234	1.0235	1.0236
210	1.0237	1.0238	1.0239	1.0240	1.0242	1.0243	1.0244	1.0245	1.0246	1.0247
220	1.0248	1.0249	1.0251	1.0252	1.0253	1.0254	1.0255	1.0256	1.0257	1.0258
230	1.0259	1.0261	1.0262	1.0263	1.0264	1.0265	1.0266	1.0267	1.0268	1.0270
240	1.0271	1.0272	1.0273	1.0274	1.0275	1.0276	1.0277	1.0279	1.0280	1.0281
250	1.0282	1.0283	1.0284	1.0285	1.0286	1.0287	1.0288	1.0290	1.0291	1.0292
260	1.0293	1.0294	1.0295	1.0296	1.0297	1.0298	1.0299	1.0300	1.0302	1.0303
270	1.0304	1.0305	1.0306	1.0307	1.0308	1.0309	1.0310	1.0311	1.0313	1.0314
280	1.0315	1.0316	1.0317	1.0318	1.0319	1.0320	1.0321	1.0323	1.0324	1.0325
290	1.0326	1.0327	1.0328	1.0329	1.0330	1.0331	1.0332	1.0333	1.0335	1.0336
300	1.0337	1.0338	1.0339	1.0340	1.0341	1.0342	1.0343	1.0344	1.0346	1.0347
310	1.0348	1.0349	1.0350	1.0351	1.0352	1.0353	1.0354	1.0355	1.0357	1.0358
320	1.0359	1.0360	1.0361	1.0362	1.0363	1.0364	1.0365	1.0366	1.0368	1.0369
330	1.0370	1.0371	1.0372	1.0373	1.0374	1.0375	1.0376	1.0378	1.0379	1.0380
340	1.0381	1.0382	1.0383	1.0384	1.0385	1.0386	1.0387	1.0389	1.0390	1.0391
350	1.0392	1.0393	1.0394	1.0395	1.0396	1.0397	1.0398	1.0399	1.0401	1.0402
360	1.0403	1.0404	1.0405	1.0406	1.0407	1.0408	1.0409	1.0410	1.0412	1.0413
370	1.0414	1.0415	1.0416	1.0417	1.0418	1.0419	1.0420	1.0421	1.0423	1.0424
380	1.0425	1.0426	1.0427	1.0428	1.0429	1.0430	1.0431	1.0433	1.0434	1.0435
390	1.0436	1.0437	1.0438	1.0439	1.0440	1.0441	1.0443	1.0444	1.0445	1.0446
400	1.0447	1.0448	1.0449	1.0450	1.0451	1.0452	1.0453	1.0454	1.0455	1.0456
410	1.0457	1.0459	1.0460	1.0461	1.0462	1.0463	1.0464	1.0465	1.0466	1.0467
420	1.0468	1.0469	1.0470	1.0471	1.0472	1.0474	1.0475	1.0476	1.0477	1.0478
430	1.0479	1.0480	1.0481	1.0482	1.0483	1.0484	1.0486	1.0487	1.0488	1.0489
440	1.0490	1.0491	1.0492	1.0493	1.0494	1.0495	1.0496	1.0498	1.0499	1.0500
450	1.0501	1.0502	1.0503	1.0504	1.0505	1.0506	1.0507	1.0509	1.0510	1.0511
460	1.0512	1.0513	1.0514	1.0515	1.0516	1.0517	1.0518	1.0520	1.0521	1.0522
470	1.0523	1.0524	1.0525	1.0526	1.0527	1.0528	1.0529	1.0530	1.0532	1.0533
480	1.0534	1.0535	1.0536	1.0537	1.0538	1.0539	1.0540	1.0542	1.0543	1.0544
490	1.0545	1.0546	1.0547	1.0548	1.0549	1.0550	1.0552	1.0553	1.0554	1.0555
500	1.0556									

Note:—Factors taken from C. N. G. A. Bul. TS-354 based on a gas having a specific gravity of .660 and an average flowing temperature of 50° F. CAUTION:—If conditions vary materially from 50° F. and 0.66 specific gravity, compute F_{pv} for actual temperature and specific gravity by reference to Bulletin T. S. 402 of C. N. G. A.—as an example: F_{pv} of 1.050 from above table may be in error by 0.01, or more, if temperature is outside range of 25° F. to 85° F. or if specific gravity is outside range of 0.605 to 0.705.

From Report No. 4, Practical Methods Committee, Appalachian Gas Measurement Short Course, School of Mines, West Virginia University, 1950.

MONTHLY AVERAGE FLOWING GAS TEMPERATURES FOR APPALACHIAN AREA

Closing Date	Monthly Average Flowing Gas Temperatures											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	37	33	34	38	48	58	66	70	69	63	55	44
2	37	33	34	38	48	58	66	70	69	63	54	44
3	36	33	34	39	48	58	66	70	68	63	54	44
4	36	33	34	39	49	58	66	70	68	62	54	43
5	36	33	34	39	49	59	66	70	68	62	53	43
6	36	33	34	40	49	59	66	70	68	62	53	43
7	36	33	34	40	50	59	66	70	68	62	53	43
8	36	33	35	40	50	60	67	70	67	61	52	42
9	36	33	35	41	50	60	67	70	67	61	52	42
10	36	33	35	41	51	60	67	70	67	61	51	42
11	36	33	35	41	51	60	67	70	67	60	51	42
12	36	33	35	42	51	61	67	69	67	60	51	41
13	35	33	35	42	52	61	67	69	67	60	50	41
14	35	33	35	42	52	61	67	69	66	60	50	41
15	35	33	36	43	52	61	67	69	66	59	50	41
16	35	33	36	43	52	62	68	69	66	59	49	40
17	35	33	36	44	53	62	68	69	66	59	49	40
18	35	33	36	44	53	62	68	69	66	59	49	40
19	35	33	36	44	53	62	68	69	66	58	48	40
20	35	33	36	44	54	63	68	69	65	58	48	40
21	34	33	36	45	54	63	68	69	65	58	47	39
22	34	33	37	45	54	63	68	69	65	58	47	39
23	34	33	37	45	55	64	69	69	65	57	47	39
24	34	33	37	46	55	64	69	69	65	57	46	39
25	34	33	37	46	55	64	69	69	64	57	46	38
26	34	33	37	46	56	64	69	69	64	57	46	38
27	34	34	37	46	56	65	69	69	64	56	45	38
28	34	34	37	47	56	65	69	69	64	56	45	38
29	33		38	47	57	65	69	69	64	56	45	37
30	33		38	47	57	66	70	69	64	55	44	37
31	33		38		57		70	69		55		37

With permission, Columbia Gas System Inc.

REFORMED GAS

THE U.G.I. CYCLIC CATALYTIC REFORMING PROCESS
12'-0" O.D. TWO SHELL STANDARD UNIT
Estimated Operating Data
PART I. PRODUCTION FOR LOW GRAVITY GAS SUBSTITUTE

FEED MATERIAL FOR HEATING, PROCESS AND ENRICHMENT	NATURAL GAS		BUTANE	
QUALITY OF GAS				
Btu of feed per cu. ft.	1040		3200	
Specific gravity of feed	0.62		2.02	
Btu of reformed gas	280		287	
Specific gravity of reformed gas	0.48		0.41	
Btu of sendout gas	540		540	
Specific gravity of sendout gas	0.52		0.54	
H_2 to inerts ratio-sendout gas	2.00		4.47	
PRODUCTION				
Reformed gas—Mcf per day	11,400		8,300	
Sendout gas—Mcf per day	17,300		9,100	
FEED MATERIALS USED PER MCF				
Reformed gas basis:				
Total cu. ft.	337			
Total gallons			3.55	
Sendout gas basis:				
Total cu. ft.	564			
Total gallons			5.97	
GAS ANALYSES—%	**REFORMED**	**SENDOUT**	**REFORMED**	**SENDOUT**
Illuminants	—	—	—	—
CO	13.5	8.9	16.0	14.6
H_2	54.3	35.7	64.0	58.5
CH_4	6.8	34.9	5.2	4.8
C_2H_6	0.3	0.2	—	—
Hi-paraffins	—	1.8	—	8.7
CO_2	8.1	5.8	7.0	6.4
O_2	0.3	0.7	0.4	0.3
N_2	16.7	12.0	7.4	6.7

(Continued on next page)

PART II. PRODUCTION FOR MEDIUM GRAVITY GAS SUBSTITUTE

FEED MATERIAL FOR HEATING, PROCESS AND ENRICHMENT	NATURAL GAS		BUTANE	
QUALITY OF GAS				
Btu of feed per cu. ft.	1040		3200	
Specific gravity of feed	0.62		2.00	
Btu of reformed gas	239		259	
Specific gravity of reformed gas	0.60		0.48	
Btu of sendout gas	540		540	
Specific gravity of sendout gas	0.61		0.63	
H_2 to inerts ratio-sendout gas	0.96		2.52	
PRODUCTION				
Reformed gas—Mcf per day	15,300		9,300	
Sendout gas—Mcf per day	24,500		10,300	
FEED MATERIALS USED PER MCF				
Reformed gas basis:				
Total cu. ft.	279			
Total gallons			3.20	
Sendout gas basis:				
Total cu. ft.	550			
Total gallons			5.92	
GAS ANALYSES—%	**REFORMED**	**SENDOUT**	**REFORMED**	**SENDOUT**
Illuminants	—	—	—	—
CO	11.2	7.0	14.4	13.0
H_2	40.3	25.1	57.6	52.1
CH_4	7.9	38.4	4.7	4.3
C_2H_6	0.4	0.2	—	—
Hi-paraffins	—	2.0	—	9.6
CO_2	6.4	4.5	7.7	7.0
O_2	0.4	1.0	0.4	0.3
N_2	33.4	21.8	15.2	13.7

PART III. PRODUCTION FOR HIGH GRAVITY GAS SUBSTITUTE

FEED MATERIAL FOR HEATING, PROCESS AND ENRICHMENT	NATURAL GAS		BUTANE	
QUALITY OF GAS				
Btu of feed per cu. ft.	1040		3200	
Specific gravity of feed	0.62		2.00	
Btu of reformed gas	186		236	
Specific gravity of reformed gas	0.69		0.51	
Btu of sendout gas	540		540	
Specific gravity of sendout gas	0.67		0.66	
H_2 to inerts ratio-sendout gas	0.63		1.98	
PRODUCTION				
Reformed gas—Mcf per day	19,000		9,800	
Sendout gas—Mcf per day	32,500		11,000	
FEED MATERIALS USED PER MCF				
Reformed gas basis:				
Total cu. ft.	239			
Total gallons			3.02	
Sendout gas basis:				
Total cu. ft.	565			
Total gallons			5.94	
GAS ANALYSES—%	**REFORMED**	**SENDOUT**	**REFORMED**	**SENDOUT**
Illuminants	—	—	—	—
CO	8.8	5.1	13.6	12.2
H_2	32.8	19.2	54.4	48.7
CH_4	8.6	41.9	4.4	4.0
C_2H_6	0.4	0.2	—	—
Hi-paraffins	—	2.2	—	10.3
CO_2	6.4	4.3	8.1	7.3
O_2	0.4	0.9	0.3	0.3
N_2	42.6	26.2	19.2	17.2

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GAS ODORANT CHARACTERISTICS

Information furnished by manufacturers

ODORANT CHARACTERISTIC	NATURAL GAS ODORIZING CO., INC.	SHARPLES CHEMICALS, INC.			
	Captan	Spotleak No. 1008	Spotleak No. 1009	Pentalarm No. 86	Pentalarm No. 1004
Specific gravity	0.835	0.83	0.81	0.84	0.84
Molecular wt., av. of mercaptans present	——	77	88	104	88
Weight/gal., lbs.	7.0	6.7	6.7	7.0	7.0
Viscosity, centistokes—at 60° F	0.548	——	——	——	——
—at 77° F	——	0.53	0.64	0.69	0.58
Reid vapor press., at 100° F, psi	5.0	5.3	4.9	1.5	8.8
Distillation	Start 125° F	——	——	——	——
	95% 265° F	——	——	——	——
	End 340° F	——	——	——	——
—— °F, 2%	——	120	120	221	122
—— °F, 95%	——	270	180	266	240
Volatility, lbs/MMcf		70 psi 700 psi	70 psi 700 psi	70 psi 700 psi	70 psi 700 psi
—40%	——	2,400 240	3,800 380	500 50	520 52
—80%	——	6,800 680	11,000 1,100	1,760 176	1,880 188
Freezing point, °F	——	<—50	<—50	<—50	<—50
Flash point, open cup, °F	——	<0	<0	50	<0
Mercaptan cont., % by wt.	94	94	94	90	94
Mercaptan sulfur cont., % by vol.	33	33	35	28	34
Toxicity at normal concentration	——	negligible	negligible	negligible	negligible
Solubility in water, % mercap. sulf. content in sat. sol. at 77° F	——	0.060	0.040	0.010	0.015
Recommended odor.-rate, lbs/MMcf	0.25-1.00	0.25-1.00	0.25-0.75	0.50-1.50	0.50-1.25
Sulfur contribution at rec. rate, grains/100 cf	——	0.058-0.232	0.06-0.183	0.098-0.294	0.120-0.300

ODORANT CHARACTERISTIC	ORONITE CHEMICAL COMPANY			
	Calodorant	Calodorant "C"	Calodorant "C" Special	Alert "80"
Specific gravity	0.78	1.0	0.878	0.830
Molecular weight	——	88	104	——
Weight/gal., lbs.	6.5	8.34	7.31	6.9
Viscosity, centistokes, 77° F	0.70	0.94	0.82	0.48
—— 32° F	0.95	1.33	——	0.55
—— 0° F	1.2	1.85	——	0.66
Reid vapor press., at 100° F, psi	3.0	——	——	9.0
Distillation (ASTM D-86)				
50% recovered	230° F	——	250° F	——
70% recovered	260° F	——	275° F	——
90% recovered	309° F	——	330° F	——
End point	360° F	263° F	360° F	——
Recovered	99%	——	——	——
Flash point	—29° F	64° F	——	——
Freezing point	——	—102° C	——	——
Solubility in water, % by vol.	0.05	0.07	——	——
Sulfur contribution, grains/100 cf				
at 2 gals/MMcf	0.41	——	——	——
at ½ lb/MMcf	——	0.12	——	——
	——	——	0.14	——

ANALYSES OF COAL TYPES FREQUENTLY USED IN, OR SUITABLE FOR BY-PRODUCT COKE OVENS[1]

Name of coal	Proximate analysis (on coal as received)				Ultimate analysis (on dry coal)					Btu value (dry coal)	Estimated coke yield (total), per cent on coal as received	Estimated gas yield, Btu in gas per lb coal
	Moisture	Volatile matter	Fixed carbon	Ash	Carbon	Hydrogen	Oxygen	Sulphur	Nitrogen			
Pennsylvania:												
Connellsville[2]	2.40	31.00	61.38	7.22	78.50	4.67	6.82	0.97	1.62	14,230	71.0	3,100
Lower Connellsville	2.00	32.20	58.00	7.80	77 80	5.20	6.33	1.09	1.63	14,100	70.0	3,200
Westmoreland	1.00	35.00	57.60	6.40	79.60	5.36	6.14	0.90	1.60	14,320	68.0	3,350
Pittsburgh[2]	3.03	35.22	55.36	6.39	79.45	5.34	5.94	1.23	1.45	14,230	68.5	3,300
Freeport[2]	2.66	34.35	56.42	6.57	79.13	5.34	6.18	1.02	1.58	14,180	69.0	3,300
Somerset (Orenda)[2]	3.77	16.26	71.06	8.91	81.96	4.15	2.22	0.81	1.60	14,075	81.0	2,600
Clearfield—Cambria (Lower Kittanning)[2]	2.00	21.17	70.90	5.93	84.10	4.60	2.72	1.23	1.42	14,800	78.5	2,680
West Virginia:												
Boomer[2]	2.96	33.57	59.18	4.29	82.45	5.32	5.36	0.80	1.65	14,840	69.0	3,300
Cabin Creek (Kanawha)	2.70	31.30	59.79	6.21	80.38	4.69	6.79	0.59	1.17	14,600	71.0	3,300
No. 2 gas[2]	2.52	34.86	56.42	6.20	80.86	5.15	5.16	0.87[4]	1.60	14,500	69.0	3,300
Fairmont[2]	2.51	37.66	53.25	6.58	78.63	5.29	6.56	1.23	1.54	14,130	66.0	3,350
Pocahontas[2]	2.60	16.39	76.38	4.63	86.79	4.22	2.33	0.78	1.13	15,020	81.0	2,650
New River[2]	3.51	24.76	69.00	2.73	86.08	4.95	3.91	0.60	1.63	15,220	75.0	2,750
Elkins[2]	1.40	26.40	62.92	9.28	79.03	4.74	3.85	1.52	1.45	14,020	75.0	2,850
Virginia:												
Tazewell Co. (Seaboard)[2]	3.13	29.00	61.77	6.10	82.63	4.82	4.23	0.60	1.42	14,670	71.0	3,100
Toms Creek[2]	2.29	32.87	59.62	5.22	82.67	5.05	4.78	0.55	1.61	14,810	70.0	3,200
Wise Co. (Roda)	2.00	34.90	60.90	2.20	84.50	5.27	5.85	0.55	1.63	14,990	69.0	3,300
Eastern Kentucky:												
Elkhorn[2]	2.91	36.33	57.53	3.23	82.26	5.49	6.71	0.57	1.64	14,650	66.0	3,450
Coxton[2]	3.18	37.21	56.30	3.31	81.50	5.30	7.10	0.96	1.72	14,620	65.0	3,450
Benham[2]	2.50	37.52	57.63	2.35	83.01	5.42	7.07	0.53	1.56	14,960	65.5	3,500
Tennessee:												
Jellico[2]	3.87	38.03	55.18	2.92	80.34	5.54	7.90	1.13	2.05	14,250	63.0	3,400
Alabama:												
Pratt Seam[2]	2.20	28.83	62.88	6.09	81.69	4.97	3.86	1.66	1.59	14,550	72.0	3,000
Tuscaloosa[2]	2.62	24.18	64.11	9.09	79.61	4.55	4.33	0.66	1.52	14,090	75.0	2,700
Illinois:												
Franklin Co. (Orient)[2]	9.93	33.13	48.77	8.17	74.47	4.84	9.22	0.83	1.57	13,200	61.0	2,900
Indiana:												
Ayrshire[2]	12.31	35.05	46.54	6.10	75.87	5.19	9.15	1.11	1.72	13,530	60.0	2,950
Colorado:												
Trinidad[2]	4.29	36.51	52.03	7.17	77.24	5.12	8.09	0.61	1.45	13,670	64.0	3,150
Utah:												
Sunnyside[2]	4.06	37.99	49.89	8.06	74.95	5.43	8.49	1.20	1.53	13,380	63.0	3,200
Washington:												
Roslyn	3.77	37.69	47.05	11.49	72.92	5.36	7.71	0.49	1 58	13,262	63.0	3,100

Most of these analyses except where noted are of face samples taken in the mine; usually car deliveries to to the consumer run 2% to 3% higher in ash.

[1] Prepared by Dr. H. C. Porter, Consulting Engineer, Philadelphia.
[2] Mine sample, analysis by U.S. Bureau of Mines.
[3] Car sample, average of 10 cars, analysis by U.S. Bureau of Mines.

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PRODUCTS OF HI AND LOW TEMPERATURE CARBONIZATION

Yields of High Temperature, Low Temperature and Complete Gasification Processes

Process	Yield Ammonium Sulphate	Yield Light Oil Benzol Tobol, Xylol	Yield Tar	Yield Gas	Yield Coke
High Temperature Distillation	20–24 lbs. Per Ton	3 plus gals. Per Ton	8–12 gals. Per Ton	10,000–11,500 Cu.Ft. Per Ton 500–560 Btu Per Cu.Ft.	1300–1400 lbs. Per Ton Suitable for Metallurgical Processes and Domestic Fuel
Low Temperature Distillation	16–20 lbs. Per Ton	3–5 gals. Per Ton	20–28 gals. Per Ton	5000–6000 Cu.Ft. Per Ton 500 to 900 Btu Per Cu.Ft.	1400 lbs. plus Per Ton Domestic Fuel May have to be briquetted
Complete Gasification	75 lbs. Per Ton	1 gal. plus Per Ton	25 gals. Per Ton	100,000 Cu.Ft. plus Per Ton Below 200 Btu's Per Cu.Ft.	None

ANALYSES OF SELECTED COALS OF VARIOUS RANKS

"As received" basis

Rank*	State	Seam	Proximate analysis, %				Ultimate analysis, %					Heating value, B.t.u./lb.
			Moisture	Volatile matter	Fixed carbon	Ash	Carbon	Hydrogen	Oxygen	Sulfur	Nitrogen	
Anthracitic:												
Meta-anthraeite	Rhode Island	Uncorrelated	1.0	4.0	66.7	28.3	...	..	...	..	..	9,620
Anthracite	Pennsylvania	Mammoth	2.3	3.1	87.7	6.9	86.7	2.2	2.9	0.5	0.8	13,540
Anthracite	Pennsylvania	Big Lykens	2.1	7.5	80.3	10.1	80.9	3.3	4.2	0.5	1.0	13,480
Semianthracite	Virginia	Merrimac	2.2	12.4	67.4	18.0	72.4	3.6	4.7	0.5	0.8	12,270
Bituminous:												
Low-volatile	West Virginia	Pocahontas No. 3	3.5	18.2	74.4	3.9	84.0	4.8	5.6	0.6	1.1	14,550
Medium-volatile	West Virginia	Sewell	3.1	25.0	66.8	5.1	...	..	...	1.3	..	14,290
High-volatile A	Pennsylvania	Pittsburgh	2.6	30.0	58.3	9.1	76.6	5.2	6.2	1.3	1.6	13,610
High-volatile A	Kentucky	Elkhorn	3.1	35.0	58.9	3.0	79.2	5.7	10.0	0.6	1.5	14,290
High-volatile B	Ohio	Middle Kittanning	8.2	36.1	48.7	7.0	68.4	5.6	16.4	1.2	1.4	12,160
High-volatile B	Kentucky	No. 6	7.2	39.8	48.8	4.2	71.5	5.8	14.3	2.6	1.6	12,950
High-volatile C	Illinois	No. 2	12.1	40.2	39.1	8.6	62.8	5.9	17.4	4.3	1.0	11,480
High-volatile C	Indiana	No. 6	12.4	36.6	42.3	8.7	63.4	5.7	18.6	2.3	1.3	11,420
Subbituminous:												
Subbituminous A or high-volatile bituminous C	Wyoming	Uncorrelated	16.5	34.2	38.1	11.2	...	..	...	2.1	..	9,740
Subbituminous B	Wyoming	Monarch	23.2	33.3	39.7	3.8	54.6	6.4	33.8	0.4	1.0	9,420
Subbituminous C	Wyoming	Uncorrelated	24.6	27.7	39.9	7.8	...	..	...	1.1	..	8,610
Lignitic:												
Lignite	North Dakota	Beulah	34.8	28.2	30.8	6.2	42.4	6.7	43.3	0.7	1.7	7,210

*According to A.S.T.M. method of classification.

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CLASSIFICATION OF FUELS

General Division	Primary Fuels	Secondary Fuels	
	Natural	Manufactured	By-Product
Solid	Anthracite coal Bituminous coal Lignite Peat Wood	Semi-coke (low temperature coal distillate) Coke Charcoal Briquettes: Coal slack and culm; Lignite; Peat; Sawdust; Petroleum residue Pulverized coal	Charcoal—low temperature distillation of wood Wood refuse—shavings, trimmings, tan bark, sawdust, etc. Bagasse—refuse sugar cane Anthracite culm—silt refuse of anthracite screening Coke Breeze: By-product coke—screenings; Petroleum coke—petroleum residue Waste Materials from Grain: Corn; Barley; Wheat; Buckwheat; Sorghum
Liquid	Petroleum	Gasoline Kerosene Alcohol Colloidal fuels Fuel oil: Residual oils; Distillate oils; Crude petroleum Naphtha Vegetable oils: Palm; Cottonseed	Coal distillates: Tar; Naphthalene; Pitch; Benzol — coke manufacture Acid sludge—petroleum refining residue Sulphite waste liquor—pulp mill waste
Gaseous	Natural Gas	Producer gas Water gas Carburetted water gas Coal gas Oil gas Reformed natural gas Butane[a] Propane[a] Acetylene Hydrogen	Blast furnace gas—pig iron manufacture Coke-oven gas[b]—coke manufacture Oil refinery gas Sewage gas—sewage sludge

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BULK DENSITY OF COAL AND COKE

(Spiers, Technical Data on Fuel)

Fuel	Bulk Density (Pounds per cu. ft.)	
Anthracite	55—60	
Bituminous Coal	50—55	
Steam Coal	50—55	
	¾—1½ In.	Rough
Coke oven coke	26—30	29—32
Horizontal coke	23—26	25—28
Vertical coke	21—22	23
Low temperature coke	19	20

Data refer to fuel broken ready for use and of normal ash and moisture content.

OPERATING RESULTS, BY-PRODUCT COKE OVENS[1]

	Utica	Philadelphia
Coal used, per cent volatile matter (ash- and moisture-free)[2]	37.8	30.1
Coal charge, tons	6.86	17 9
Coking time (average), hr (gross)	12.6	16.46
Width of ovens (average), in.	13½	17¼
Coke yield, per cent dry	70.2	74.0
Gas, cu ft per lb dry coal	5.66	5.36
Gas, Btu per cu ft	584	577
Gas, Btu per lb dry coal	3,305	3,093
Producer fuel, dry, per ton coal, lb	292	215
Producer fuel, combustible, per ton coal, lb	253	200
Producer fuel used, cu ft per lb coal (at 130 Btu)	9.99	7.52
Yield tar, gal per ton	12.35	8.16
Yield sulphate, lb per ton	24.68	20.92 (Diluted with 11% producer gas)
Gas analysis:		
CO_2, per cent	2.2	1.8
Ill., per cent	4.0	3.3
O_2, per cent	0.8	0.3
CO, per cent	6.3	8.5
CH_4, per cent	32.1	24.7
H_2, per cent	46.5	51.0
N_2, per cent	8.1	10.4
	100.0	100.0

Data assembled by H. C. Porter, Philadelphia.

[1] Actual plant data submitted by The Koppers Company, Pittsburgh, Pa., for two plants, Utica, N. Y. (consisting of 21 small-size ovens built in 1924), and Philadelphia, Pa. (consisting of 74 large-size ovens built in 1928), both plants being Becker type Koppers ovens, fired by producer gas. The Utica results are taken from the official report of A. G. A. Carbonization Plant Tests made in 1925 for comparison of different types of plant, operating on the same coal. The Utica ovens were the first of their size and type to be built and on that account were not operating at the time to the best advantage. The Utica results cover a period of 21 days. The Philadelphia results are averages for a five-month period.

[2] At Utica, 100 per cent volatile Pittsburgh coal; at Philadelphia a mixture averaging 76 per cent Powellton (W. Va.) and 24 per cent Pocahontas.

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CALCULATING HEATING VALUE OF COAL FROM ANALYSIS

By far the most satisfactory way of determining the heating value of a coal is by the bomb calorimeter. Where only the analysis is available the following computations of the approximate heating value of the coal may be made.

Ultimate Analysis:

$$\text{B.t.u. per lb.} = 146\ C + 620\ (H - \frac{O}{8}) + 40.5\ S$$

where

C = per cent of carbon.
H = per cent of hydrogen.
O = per cent of oxygen.
S = per cent of sulphur.

With bituminous and anthracite coals the calculated values will usually be within 1½ per cent of the observed value. The higher the percentage of oxygen the greater is the error apt to be.

Proximate Analysis:

B.t.u. per lb. = (C × c + V × v)—(16 M + 30 A + 39 S) where

C = per cent of fixed carbon.
V = per cent of volatile combustible.
M = per cent of moisture.
A = per cent of ash.
S = per cent of sulphur.
c — see Table I.
v — see Table II.

Table I
Values of c.

For Anthracite Coal	141
For Bituminous Coal	140
For Lignite	95
For Coke	130

Table II
Values of v.

Per Cent Vol. Comb.	"v"	Per Cent Vol. Comb.	"v"
1	240.5	27	180.5
2	236.4	28	178.8
3	232.5	29	177.2
4	228.8	30	175.5
5	225.3	31	173.9
6	221.9	32	172.3
7	218.6	33	170.7
8	215.4	34	169.2
9	212.3	35	167.8
10	210.3	36	166.6
11	208.3	37	165.5
12	205.4	38	164.4
13	204.6	39	163.3
14	202.7	40	162.2
15	200.9	41	161.1
16	199.2	42	160.0
17	197.5	43	158.9
18	195.7	44	157.8
19	194.0	45	156.7
20	192.3	46	155.6
21	190.6	47	154.5
22	188.9	48	153.4
23	187.2	49	152.3
24	185.5	50	151.2
25	183.8	51	150.1
26	182.1	52	149.0

H. H. Clark—American Gas Light Journal.

Purifier Reactions

(1) $Fe_2O_3 \cdot H_2O + 3H_2S = Fe_2S_3 + 4H_2O$.
(2) $Fe_2O_3 \cdot H_2O + 3H_2S = 2FeS + S + 4H_2O$.

Revivification of fouled oxide:

(3) $2Fe_2S_3 + 3O_2 + 2H_2O = 2Fe_2O_3 \cdot H_2O + 6S$.
(4) $4FeS + 3O_2 + 2H_2O = 2Fe_2O_3 \cdot H_2O + 4S$.

Purifier reaction (1) is the desirable one in gas purification. It occurs under alkaline conditions. The ferric sulphide (Fe_2S_3) is readily converted back to the hydrate oxide with oxygen in the presence of suitable amounts of moisture according to reaction (3).

Purification reaction (2) takes place under neutral or slightly acid conditions. The ferrous sulphide (FeS) may also be oxidized to hydrated ferric oxide according to the equation (4). The formation of ferrous sulphide is undesirable because at slightly elevated temperatures, caused by the heat given off in the reaction between oxide and H_2S, the ferrous sulphide combines with free sulphur forming iron disulphide. FeS_2 as follows:

$$(5)\quad FeS + S = FeS_2$$

FeS_2 is inert and is not reoxidized to hydrated oxide. At 100° F. ferrous sulphide is oxidized to ferrous sulphate:

$$(6)\quad FeS + 2O_2 = FeSO_4$$

Ferrous sulphate in the presence of water reacts acid. To correct this condition some manufacturers of purification material request that the plants submit a gallon sample of the fouled oxide for a complete analysis immediately after it has been discharged from the box. If the oxide is found to be sour, in other words less than a pH of 7, it is recommended that slacked lime be forked into the material before recharging it into the box. Also from the contaminate content of the oxide it can be determined whether naphthalene, cyanogen, light oils and tars are being properly removed by the gas cleaning equipment. Finally, the amount of combined sulphur present in the sample indicates whether sufficient air is being added to the gas for revivification *in situ*.

Types of "Oxide"

There are three types of oxide used for gas purification. They are Natural Iron Ores, Rusted Cast Iron Borings and Precipitated Oxides.

Capacity of Purifiers

The primary factors in purifier capacity are: time of contact and the amount of H_2S in the unpurified gas.

There are several rules or formulas for calculating purifying capacity. Some specify so many square feet of cross sectional area per unit volume of gas passed in a given time, others include the depth of oxide. A formula which allows for the several factors is the Semet-Solvay Formula, shown here.

Less complicated rules are those given by E. L. Sweeney, G. E. Seil and T. P. Keller.

Sweeney recommends a purifier capacity of 5,000 bushels of active oxide, or 6,000 bushels of normal oxide per million cu. ft. of maximum day output.

Seil says that it is customary to figure on 5 bushels of oxide sponge per 1000 cu. ft. of gas per day, which is substantially the same as Sweeney's recommendation.

Keller suggests purifier capacity based on 30 cu. ft. of gas per hour per bushel of oxide in each box, and recommends no less than a 4 box series in any plant operating continuously. However, in a plant where the gas temperature moisture, cleaning and other conditions are favorable, the quantity of gas handled may be as high as 100 cu. ft. per hour per bushel per box.

Miscellaneous Notes

Clean gas and clean oxide are essential to efficient purification.

Selection of oxide is largely a local matter, as there are many suitable oxides from which one may choose. The main considerations are:

1. The material should contain no metallic iron or steel and the mass should be easily permeable to the gas.
2. The concentration of iron oxide may vary from 5 pounds to 15 pounds Fe_2O_3 per bushel, depending upon local conditions.
3. Care should be taken that the oxide does not take fire or be violently heated.
4. Do not allow oxide to dry out while lying around or in the boxes. Once it becomes too dry, it is difficult to get the material to absorb the proper amount of moisture.

The activity of oxide increases with an increase in temperature. A temperature range of from 92° to 100° F. is very satisfactory. For proper removal of tar and oils it is advantageous to cool the gas to 60° F. or lower. If the gas reaches the purifiers at a temperature of 60° F. or lower, the temperature can be easily raised to 92° F. or 100° F. by introducing steam into the gas at the inlet to the purifiers. This will saturate the gas at the higher temperatures and prevent drying the oxide. At a temperature of 60° F. most oxides are quite active and if the oxide is clean it will ultimately remove more sulphur even at 40° or 50° F. than material saturated with tar.

When oxide throws excessive back pressure, one remedy is to take off the cover of the box and remove the impervious crust. This can only be accomplished when the gas flow is in at the top and out at the bottom, and is one reason why it is distinctly advantageous to have one directional gas flow. Likewise in down

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SEMET-SOLVAY ENGINEERING CORPORATION GAS PURIFIER FORMULA BASED ON ORIGINAL STEERE ENGINEERING COMPANY FORMULA

$$2A = \frac{G \times S}{3{,}000 \times (D + C)}$$

$$G = \frac{3{,}000 \times (D + C) \times A}{S}$$

Where G = maximum quantity of gas in cubic feet (corrected to 60° F.) to be purified per hour.

S = factor for grains of hydrogen sulphide (H_2S) per 100 cu. ft. of unpurified gas, as given in the table below.

D = ½ the total depth in feet of oxide through which the gas passes consecutively in the purifier set, and is abtained by multiplying the depth of such oxide per box by the number of boxes in series in the set. Where a single "catch box" is used for two or more sets, disregard the catch box in obtaining factor "D."

A = cross sectional area in square feet of the oxide through which the gas passes on its way through any one box, in series of a set.

C = factor, 4 for two-box, 8 for three-box, and 10 for four-box series, respectively. Where a single catch box is used for two two-box sets, use factor C = 6.

3,000 = assembling constant.

Factor corresponding to the value of S expressed in grains H_2S per 100 cu. ft. unpurified gas is:

Grains	Factor
1,000 or more	720
900	700
800	675
700	640
600	600
500	560
400	525
300	500
200 or less	480

flow boxes any deposition of moisture is more evenly distributed when the moisture is draining from the box in the direction of the gas flow and not counter current to it. Where an impervious layer cannot be partially removed, it is necessary to dump the entire box.

Most oxide manufacturers will furnish oxide of various degrees of coarseness dependent upon whether the local plant condition necessitates special material due to dry gases or to tar contaminated gas.

When new or comparatively new oxide is removed from the box, it must never be left in piles, but should be spread out in a layer from 12″ to not over 18″ deep; otherwise it may take fire. The purifier should be completely emptied and no oxide left in it over night.

The alkalinity of oxide is important for efficient purification. New material should be sufficiently alkaline to show a pH value of from 8 to 11 when put in the boxes. A pH value of 7 or more should be maintained during the total life of the material. If the alkalinity goes below 7, sulphur and iron will combine to form a compound that will not revive. Alkalinity can be maintained by adding 4 to 6 grains of ammonia per thousand cubic feet in carburetted water gas or 10 grains per thousand cubic feet of coke oven gas where cyanogen compounds do not exceed 40 grains per hundred cubic feet. Under certain conditions oxide manufacturers will recommend the addition of a wetting agent and sufficient alkali by means of a spray in the box in order to maintain an alkaline pH throughout the life of the oxide.

There are numerous inexpensive pH sets on the market so that the smallest gas plant can purchase one for not only the control of their purifying boxes, but also for their boiler water determinations.

E. L. Sweeney (A.G.A. Production Conference 1939, published in *American Gas Journal* 1939) gives the following additional notes on dry box purification.

"For economical operation a capacity of 5000 bushels of active oxide; or 6000 bushels of normal oxide, per million cubic feet of maximum day output is satisfactory.

"A flow of gas equivalent to 30-50 cu. ft. per hour per bushel of oxide in the first box is desirable. The rate of flow should be as high as possible. It depends upon the kind of oxide used and the concentration of H_2S. If the material is of normal activity, a rate as high as 50 cu. ft. per hour per bushel of oxide in the first box can be used. A rate below 30 cu. ft. will, in most cases, eventually result in traces of H_2S passing the system. This phenomenon is more than likely due to the thickness of the water and gas film on the surface of the oxide particles which is affected by the velocity of the gas. The diffusion rate of H_2S through this film is the controlling factor.

"A mixture of approximately 2 volumes of carrier to 1 volume of ore produces a satisfactory surface area.

"The concentration of oxygen in the outlet gas should be 0.5%-1.0%.

"The activity of an oxide increases with increase of temperature, and a range between 90°-110° F. controlled with exhaust or live steam injected into the inlet gas main has been found satisfactory.

"A rise in temperature through the system usually indicates either excess oxygen, or a deficiency in moisture, sometimes both. This condition will cause the oxide to become caked, dry and inactive, except in a few instances where the gas entering is saturated and the interval of time between dumping is comparatively short."

LEAD ACETATE TEST FOR HYDROGEN SULPHIDE

The gas shall be considered free from hydrogen sulphide (H_2S) if a strip of white paper, moistened with a solution containing 5 per cent by weight of lead acetate, is not distinctly darker than a second paper freshly moistened with the same solution, after the first paper has been exposed to the gas for 1 minute in an apparatus of approved form, through which the gas is flowing at the rate of approximately 5 cu. ft. per hour, the gas not impinging directly from a jet upon the test paper.

Bureau of Standards, Circ. 32.

SENSITIVE BASIC ACETATE

50 grams of lead acetate per liter made basic with NaOH until the precipitate first formed is dissolved. This solution stains light brown at a concentration of less than 0.04 grains of H_2S per 100 cu. ft. It is about 10 times as sensitive as the standard lead acetate paper tests.

E. L. Sweeney.

AVERAGE PROPERTIES OF LIQUEFIED PETROLEUM GAS PRODUCTS

	Commercial Propane	Industrial Propane	Commercial Butane
Vapor Pressure Lbs./Sq. In. Gauge			
at 70° F.	124	122	31
at 100° F.	192	190	59
at 105° F.	206	204	65
at 130° F.	286	282	97
Specific Gravity of Liquid (60°/60° F.)	0.509	0.511	0.582
Initial Boiling Point at 14.7 Lbs./Sq. In. Abs., °F.	−51	−51	15
Weight per Gallon of Liquid at 60° F., Lbs.	4.24	4.26	4.84
Dew Point at 14.7 Lbs./Sq. In. Abs., °F.	−46	−45	24
Specific Heat of Liquid, Btu/Lb./°F. at 60° F.	0.588	0.587	0.549
Cu. Ft. of Gas at 60° F., 30" Hg. Per Gallon of Liquid at 60° F.	36.28	36.18	31.46
Specific Volume of Gas, Cu. Ft./Lb. at 60° F., 30" Hg.	8.55	8.50	6.50
Specific Heat of Gas, Btu/Lb./°F. at 60° F. (Cp)	0.404	0.401	0.382
Specific Gravity of Gas (Air = 1) at 60° F., 30" Hg.	1.52	1.53	2.01
Ignition Temperature in Air, °F.	920-1020	920-1020	900-1000
Maximum Flame Temperature in Air, °F.	3595	3600	3615
Percent Gas in Air for Maximum Flame Temperature, %	4.2-4.5	4.2-4.4	3.3-3.4
Maximum Rate of Flame Propagation in 25 mm. Tube:			
Cms. Per Second	84.9	85.9	87.1
Inches Per Second	33.4	33.8	34.3
Limits of Inflammability in Air, Gas Per Cent in Gas-Air Mixture:			
At Lower Limit, %	2.4	2.4	1.9
At Maximum Rate of Flame Propagation, %	4.7-5.0	4.7-4.9	3.7-3.9
At Upper Limit, %	9.6	9.6	8.6
Required for Complete Combustion:			
Cu. Ft. O_2/Cu. Ft. Gas	4.9	4.9	6.3
Cu. Ft. Air/Cu. Ft. Gas	23.4	23.4	30.0
Lbs. O_2/Lb. Gas	3.60	3.59	3.54
Lbs. Air/Lb. Gas	15.58	15.52	15.3
Products of Complete Combustion:			
Cu. Ft. CO_2/Cu. Ft. Gas	3.0	3.0	3.9
Cu. Ft. H_2O/Cu. Ft. Gas	3.8	3.8	4.6
Cu. Ft. N_2/Cu. Ft. Gas	18.5	18.5	23.7
Lbs. CO_2/Lb. Gas	3.0	3.0	3.1
Lbs. H_2O/Lb. Gas	1.6	1.5	1.5
Lbs. N_2/Lb. Gas	12.0	11.9	11.8
Ultimate CO_2, % by Volume	13.9	13.9	14.1
Latent Heat of Vaporization at Boiling Point:			
Btu per Pound	185	184	167
Btu per Gallon	785	784	808
Total Heating Values (After Vaporization):			
Btu per Cubic Foot	2522	2537	3261
Btu per Pound	21560	21570	21180
Btu per Gallon	91500	91800	102600

Phillips Petroleum Company, with permission.

SPECIFICATIONS AND TEST METHODS NGAA LIQUEFIED PETROLEUM GAS

The following specifications and test methods for liquefied petroleum gases were adopted as Tentative Standards by the Natural Gasoline Association of America, effective September 1, 1940:

Commercial Propane

DEFINITION. Commercial Propane shall be a hydrocarbon product composed predominantly of propane and/or propylene and shall be free from harmful quantities of deleterious substances.

COMPOSITION. The composition of Commercial Propane shall be at least 95 per cent propane and/or propylene by liquid volume as determined by the combined results of the Vapor Pressure and Mercury Freezing Tests.

MERCURY FREEZING TEST. The residue as determined by means of the Mercury Freezing Test shall not be more than two per cent by volume.

VAPOR PRESSURE. The vapor pressure at 105° F., as determined by the Liquefied Petroleum Gas Vapor Pressure Method shall not be in excess of 225 pounds per square inch gage pressure.

SULPHUR CONTENT. The product shall be free of hydrogen sulphide and shall not contain mercaptans, or sulphur compounds, of corrosive nature. The unstenched product shall not contain total sulphur in excess of fifteen (15) grains per hundred (100) cubic feet of vapor as determined by the test for Total Sulphur in Liquefied Petroleum Gases.

WATER CONTENT. The product shall satisfactorily pass the standard Cobalt Bromide Test.

ODORIZATION. A sufficient quantity of an odorizing agent of such character as to indicate positively the presence of gas down to concentrations in air of not over one-fifth the lower limit of flammability by a distinctive odor shall be added by the manufacturer; provided, however, that odorization is not required if harmful in the use or further processing of the liquefied petroleum gas, or if odorization will serve no useful purpose as a warning agent in such use or further processing.

Commercial Butane

DEFINITION. Commercial butane shall be a hydrocarbon product composed predominantly of butanes and/or butylenes and shall be free from harmful quantities of deleterious substances.

VAPOR PRESSURE. The vapor pressure at 105° F. as determined by the Liquefied Petroleum Gas Vapor Pressure Method, shall not be in excess of 75 pounds per square inch by gage pressure.

95 PER CENT BOILING POINT. The quantity evaporated at a temperature of 34° F., corrected to a barometric pressure of 740 mm. Hg., shall be 95% or more by volume, as determined by the Open Cylinder Weathering Test.

SULPHUR CONTENT. *Same as for Commercial Propane.*

WATER CONTENT. The product shall be free of mechanically entrained water.

ODORIZATION. *Same as for Commercial Propane.*

Butane-Propane Mixtures

DEFINITION. Butane-Propane mixtures shall be hydrocarbon products composed predominantly of mixtures of butanes and/or butylenes with propane and/or propylene and shall be free from harmful quantities of deleterious substances.

VAPOR PRESSURE. *Same as for Commercial Propane.*

PRODUCT DESIGNATION. Butane-Propane mixtures shall be designated by the vapor pressure at 100° F. in pounds per square inch gage. To comply with the designation the vapor pressure of mixtures shall be within +0 lbs. —5 lbs. of the vapor pressure specified. For example, a product specified as 95 lbs. LP-G shall have a vapor pressure of at least 90 lbs. but not exceeding 95 lbs.

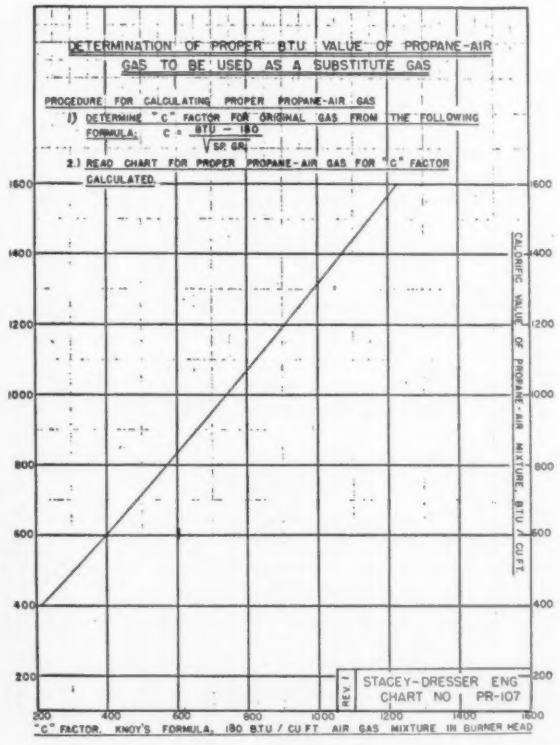
95 PER CENT BOILING POINT. *Same as for Commercial Butane.*

SULPHUR CONTENT. *Same as for Commercial Propane.*

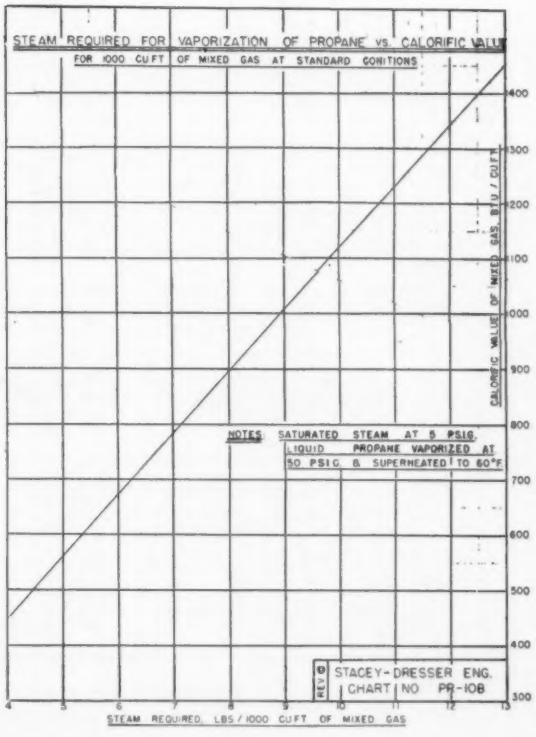
WATER CONTENT. *Same as for Commercial Butane.*

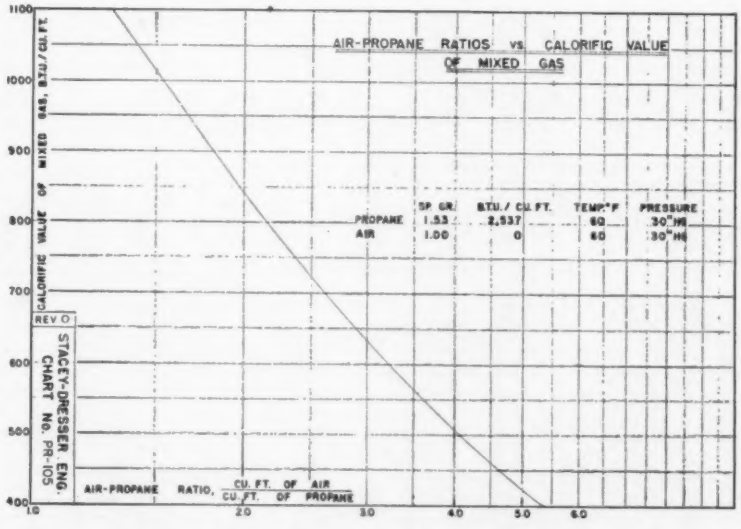
ODORIZATION. *Same as for Commercial Propane.*

KNOY'S FORMULA FOR SUBSTITUTE GAS CALCULATIONS


DETERMINATION OF PROPER BTU VALUE OF PROPANE-AIR GAS TO BE USED AS A SUBSTITUTE GAS
PROCEDURE FOR CALCULATING PROPER PROPANE-AIR GAS
1) DETERMINE "C" FACTOR FOR ORIGINAL GAS FROM THE FOLLOWING FORMULA: C = BTU − 180 / √SP. GR.
2.) READ CHART FOR PROPER PROPANE-AIR GAS FOR "C" FACTOR CALCULATED.
CALORIFIC VALUE OF PROPANE-AIR MIXTURE, BTU / CU FT.
REV 1
STACEY-DRESSER ENG.
CHART NO PR-107
"C" FACTOR, KNOY'S FORMULA, 180 BTU / CU FT AIR GAS MIXTURE IN BURNER HEAD

STEAM REQUIRED FOR VAPORIZING PROPANE


STEAM REQUIRED FOR VAPORIZATION OF PROPANE vs. CALORIFIC VALUE
FOR 1000 CU FT OF MIXED GAS AT STANDARD CONDITIONS
CALORIFIC VALUE OF MIXED GAS, BTU / CU FT.
NOTES: SATURATED STEAM AT 5 PSIG.
LIQUID PROPANE VAPORIZED AT 50 PSIG & SUPERHEATED TO 60°F
REV 0
STACEY-DRESSER ENG.
CHART NO PR-108
STEAM REQUIRED, LBS / 1000 CU FT OF MIXED GAS


AIR-PROPANE RATIOS vs. CALORIFIC VALUE OF MIXED GAS
CALORIFIC VALUE OF MIXED GAS, BTU / CU FT.
SP GR. BTU / CU FT. TEMP °F PRESSURE
PROPANE 1.53 2,537 60 30" HG
AIR 1.00 0 60 30" HG
REV 0
STACEY-DRESSER ENG.
CHART NO. PR-105
AIR-PROPANE RATIO, CU. FT. OF AIR / CU. FT. OF PROPANE

AIR-PROPANE RATIOS vs. CALORIFIC VALUE

PHYSICAL CONSTANTS OF PARAFFIN HYDROCARBONS—1945 N.G.A.A. Standard 2145

	METHANE	ETHANE	PROPANE	ISO-BUTANE	N-BUTANE	ISO-PENTANE	N-PENTANE	N-HEXANE	N-HEPTANE	N-OCTANE	N-NONANE	N-DECANE
Molecular Formula	CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_4H_{10}	C_5H_{12}	C_5H_{12}	C_6H_{14}	C_7H_{16}	C_8H_{18}	C_9H_{20}	$C_{10}H_{22}$
Molecular Weight	16.042	30.068	44.094	58.120	58.120	72.146	72.146	86.172	100.198	114.224	128.250	142.276
Melting Point @ 14.696 Lbs./sq. in. Abs.												
°C.	−182.5	−183.2	−187.7	−159.4	−138.3	−160.6	−129.7	− 95.4	− 90.6	− 56.8	− 53.7	− 29.7
	28	38	37	55	55	29	29	29	29	7	7	2
°F.	−296.5	−297.8	−305.9	−255.3	−216.9	−257.1	−201.5	−139.7	−131.1	− 70.0	− 64.7	− 21.5
Boiling Point @ 14.696 Lbs./sq. in. Abs.												
°C.	−161.4	− 89.0	− 42.1	− 11.7	− 0.5	+ 27.9	36.1	68.7	98.4	125.7	150.7	174.0
	24	38	9, 37	55	16	55	6, 15	15, 8	15, 17, 35	7	7	7
°F.	−258.5	−128.2	− 43.8	+ 10.9	+ 31.1	+ 82.2	97.0	155.7	209.1	258.1	303.3	345.2
Density of Liquid												
Specific Gravity @ 60/60° F.	0.3**	0.374	0.508	0.563	0.584	0.625	0.631	0.664	0.688	0.707	0.722	0.734
	19, 20, 21	44	41	41	23, 5, 41	13	14, 15, 41	8, 13, 34	14, 15	32	24	1
°A.P.I.	340**	247	147.0	119.8	110.8	94.9	92.7	81.6	74.2	68.6	64.5	61.3
Lb. per Gal. @ 60° F.	2.5**	3.11	4.23	4.69	4.86	5.20	5.25	5.53	5.73	5.89	6.01	6.11
Gal. per Lb. Mol @ 60° F.	6.4**	9.64	10.41	12.38	11.94	13.84	13.71	15.57	17.47	19.38	21.31	23.25
Density of Vapor												
60° F. 14.696 Lbs./sq. in. Abs.***												
Specific Gravity (Air = 1.00)	0.554	1.038	1.522	2.006	2.006	2.491	2.491	2.975	3.459	3.943	4.428	4.912
Lb./M Cu Ft.	42.27	79.23	116.2	153.1	153.1	190.1	190.1	227.1	264.0	301.0	337.9	374.9
Cu. Ft. Vapor/Gal. Liq.	59**	39.35	36.45	30.65	31.79	27.41	27.67	24.38	21.72	19.58	17.81	16.32
Ratio, Gas Vol./Liq. Vol.* **	443**	294.3	272.7	229.3	237.8	205.0	207.0	182.4	162.5	146.5	133.2	122.1
Critical Conditions												
Temperature—°C	− 82.5	+ 32.3	96.8	134.0	152.0	187.8	197.2	234.8	267.0	296.0	322.2	346.1
	24	39, 36	30	24	39	24	24	24	17	24	33	33
Temperature—°F	−116.5	+ 90.1	206.2	273.2	305.6	370.0	387.0	454.6	512.6	564.8	612.0	655.0
Pressure—Atmospheres	45.8	48.2	42.0	36.1	37.5	32.8	33.0	29.5	27.0	24.6	22.9	21.2
	24	39	30	2	39	24	24	24	17	24	33	33
Pressure—Lb./Sq In Abs.	673	708	617	530	551	482	485	434	397	361	337	312
Density Lb./Gal.	1.351	1.695	1.888	1.946	1.891	1.955	1.935	1.958	1.957	1.942	1.935	1.919
	25	39	25	25	39	25	25	25	25	52	54	54
Volume, Cu. Ft./Lb. Mol.	1.586	2.371	3.123	3.990	4.130	4.930	4.98	5.88	6.84	7.86	8.86	9.91
Gross Heat of Combustion												
B.T.U./Lb Vapor*	23,920	22,350	21,690	21,290	21,340	21,060	21,120	20,970	20,860	20,780	20,710	20,660
	3	3	3	5	3	40	3	3	3	3	3	3
B.T.U./Cu. Ft *	1,011	1,771	2,521	3,259	3,267	4,003	4,015	4,762	5,507	6,255	6,998	7,745
B.T.U./Gal. Liq. @ 60° F.		68,900	91,300	99,300	103,000	108,700	110,000	114,900	118,500	121,300	123,500	125,300
					56		56	56	56	56	56	56
Explosion Limits—Lower % in air	4.9-6-2	3.0-3.3	2.0-2.4	1.80	1.5-1.9	1.32	0.3-2.5	1.1-1.3	1.0-1.1	0.95	0.83	0.67
	31	31	31	31	31	45	31	31	31	45	45	45
Upper % in air	12.7-16.0	10.6-15.0	7.0-9.5	8.44	5.7-8.5	——	4.5-7.5	4.2-6.0	3.6-6.0	——	——	——
Cu. Ft. Air to burn 1 cu. ft. gas	9.55	16.71	23.87	31.03	31.03	38.19	38.19	45.35	52.06	59.67	66.83	73.99
Heat of Vaporiz. 14.696 Lbs./sq. in. Abs B.T.U./Lb. at B.P	245	211	183	158	166	146	153	146	138	131	125	120
	50	50	50	50	50	50	50	50	50	50	50	50
Specific Heat												
14.696 Lbs./sq. in. Abs.												
C_p Vapor B.t.u./Lb °F.	0.526	0.413	0.390	0.406	0.396	0.413	0.402	0.406	0.415	0.420	0.429	0.436
	4, 47, 49	4, 47, 49	4, 47, 49	4, 47, 49	4, 47, 49	4, 47, 49	4, 47, 49	4, 47, 49	4, 47, 49	4, 47, 49	4, 47, 49	4, 47, 49
C_v Vapor B.t.u./Lb. °F	0.402	0.347	0.346	0.373	0.363	0.387	0.376	0.384	0.397	0.404	0.415	0.424
$N = C_p/C_v$ B.t.u./Lb. °F	1.306	1.189	1.128	1.088	1.090	1.066	1.070	1.057	1.045	1.040	1.034	1.028
C_p Liquid B t.u./Lb °F.	—	—	—		0.55@32		0.55	0.536	0.522	0.519	0.518	0.517
					24		27	53	6		48	48
Vapor Pressure @ 100° F., Lb./Sq. In. Abs.	—	—	189.5	73.5	52.0	20.3	15.5	5.0	1.63	0.54	0.19	0.06
			46, 10	26, 24	22, 18	24	11, 18	24, 18	24, 18	42	42	42
Aniline Point °F.				225.7	181.2	174.0	159.3	155.5	159.1	161.1	166.1	171.5
				46	46	46	51	46	46	46	46	46
Refractive Index N_D^{20C}						1.3540	1.3577	1.3750	1.3878	1.3976	1.4056	1.4120
						51	51	51	51	51	51	43

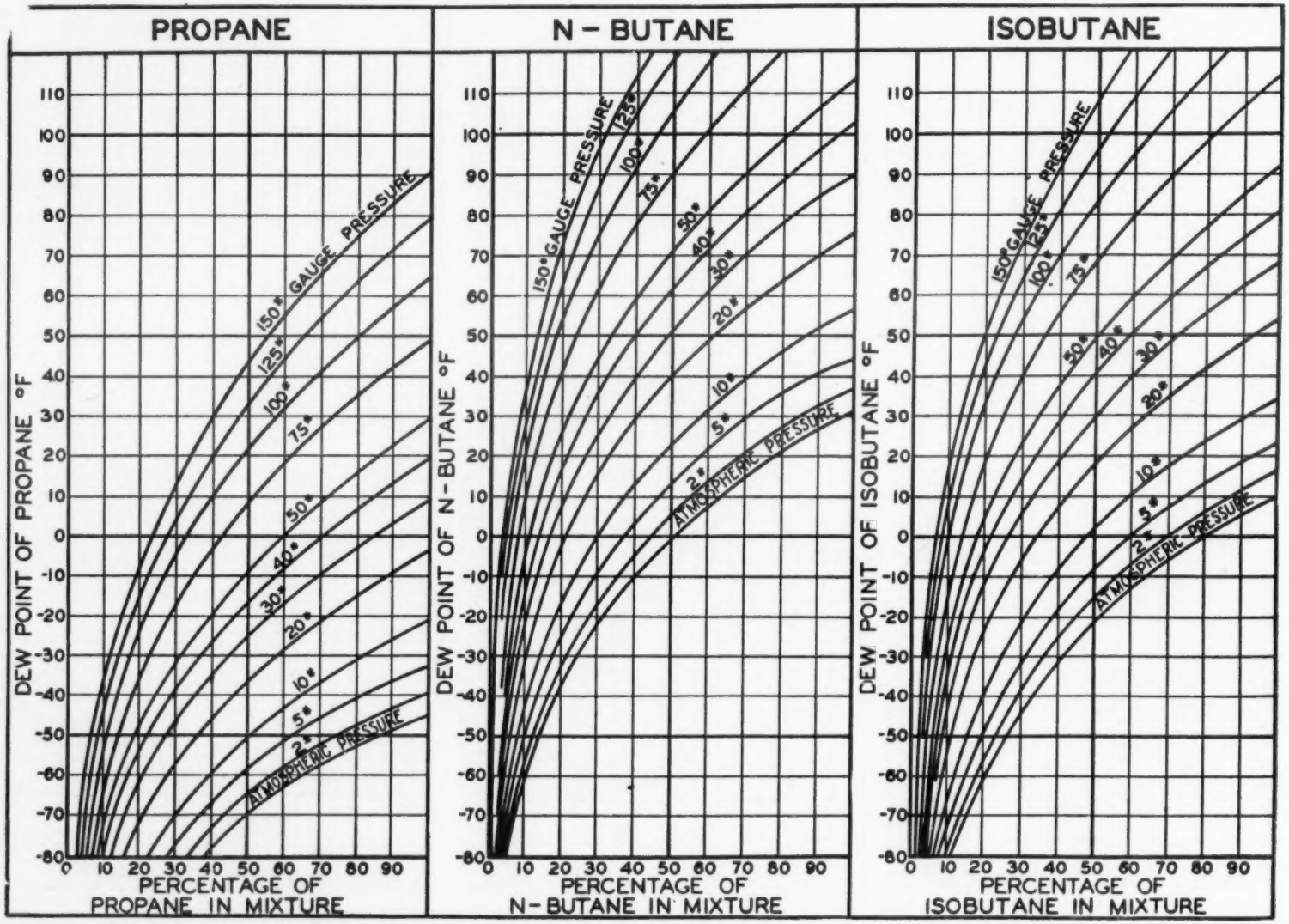
1. Sub-numerals shown with values refer to references in the bibliography. Where none are given, the values were calculated from those with references.

*Gross Heat on dry basis at 14.696 Lbs./sq. in. Abs. and 60° F To convert to water saturation basis, multiply by 0.9825

**Apparent values for dissolved Methane @ 60° F.

***Based on "perfect gas."

DEW POINTS OF PROPANE, NORMAL BUTANE AND ISOBUTANE, CARBURETTED WITH AIR



Copyright, page 38, 3rd edition Handbook Butane-Propane Gases.

N.G.A.A. SPECIFIC GRAVITY CONVERSION FACTORS (1942)

Observed Temperature Degrees Fahrenheit	OBSERVED SPECIFIC GRAVITY																														
	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.68	0.69	0.70	0.71	0.72	0.73
	CORRESPONDING SPECIFIC GRAVITIES 60° F./60° F.																														
−50															0.487	0.500	0.513	0.526	0.538	0.550	0.562	0.575	0.587	0.599								
−45															0.491	0.504	0.517	0.529	0.542	0.554	0.566	0.578	0.590									
−40															0.495	0.508	0.521	0.533	0.545	0.558	0.570	0.581	0.593									
−35															0.500	0.512	0.525	0.537	0.549	0.561	0.573	0.585	0.596									
−30															0.504	0.516	0.529	0.541	0.552	0.564	0.576	0.588	0.600									
−25															0.508	0.520	0.532	0.544	0.556	0.568	0.580	0.591										
−20														0.488	0.512	0.524	0.536	0.548	0.559	0.571	0.583	0.594										
−15														0.492	0.504	0.516	0.528	0.540	0.552	0.563	0.574	0.586	0.597									
−10													0.484	0.496	0.508	0.520	0.532	0.543	0.555	0.566	0.578	0.589	0.601									
− 5													0.488	0.500	0.512	0.524	0.536	0.547	0.559	0.570	0.581	0.593										
0												0.481	0.493	0.505	0.516	0.528	0.540	0.551	0.562	0.573	0.585	0.596	0.607	0.618	0.628	0.639	0.649	0.659	0.670	0.680	0.690	0.700
2												0.483	0.495	0.506	0.517	0.529	0.541	0.552	0.563	0.574	0.586	0.597	0.608	0.619	0.629	0.640	0.650	0.660	0.671	0.681	0.691	0.701
4												0.484	0.496	0.508	0.519	0.531	0.542	0.553	0.564	0.576	0.587	0.598	0.609	0.620	0.630	0.641	0.651	0.661	0.672	0.682	0.692	0.702
6												0.486	0.498	0.509	0.520	0.532	0.544	0.555	0.566	0.577	0.589	0.599	0.610	0.621	0.631	0.642	0.652	0.662	0.673	0.683	0.693	0.703
8												0.487	0.499	0.511	0.522	0.534	0.545	0.556	0.567	0.579	0.590	0.600	0.611	0.622	0.632	0.643	0.653	0.663	0.674	0.684	0.694	0.704
10												0.489	0.501	0.512	0.523	0.535	0.546	0.557	0.568	0.580	0.591	0.601	0.612	0.623	0.633	0.644	0.654	0.664	0.675	0.685	0.695	0.705
12												0.491	0.503	0.514	0.525	0.536	0.547	0.558	0.569	0.581	0.592	0.602	0.613	0.624	0.634	0.645	0.655	0.665	0.676	0.686	0.696	0.706
14												0.492	0.504	0.515	0.526	0.538	0.549	0.560	0.571	0.582	0.593	0.604	0.614	0.625	0.635	0.646	0.656	0.666	0.677	0.687	0.697	0.707
16												0.494	0.506	0.517	0.528	0.539	0.550	0.561	0.572	0.584	0.595	0.605	0.616	0.626	0.637	0.647	0.657	0.667	0.678	0.688	0.698	0.708
18												0.495	0.507	0.518	0.529	0.541	0.552	0.563	0.574	0.585	0.596	0.607	0.617	0.627	0.638	0.648	0.658	0.668	0.679	0.689	0.699	0.709
20											0.486	0.497	0.509	0.520	0.531	0.542	0.553	0.564	0.575	0.586	0.597	0.608	0.618	0.628	0.639	0.649	0.659	0.669	0.680	0.690	0.700	0.710
22											0.488	0.499	0.511	0.522	0.533	0.544	0.554	0.565	0.576	0.587	0.598	0.609	0.619	0.629	0.640	0.650	0.660	0.670	0.681	0.691	0.701	
24											0.490	0.501	0.512	0.523	0.534	0.545	0.556	0.567	0.578	0.588	0.599	0.610	0.620	0.630	0.641	0.651	0.661	0.671	0.682	0.692	0.702	
26											0.491	0.502	0.514	0.525	0.536	0.547	0.557	0.568	0.579	0.590	0.600	0.611	0.621	0.632	0.642	0.652	0.662	0.673	0.683	0.693	0.703	
28											0.493	0.504	0.515	0.526	0.537	0.548	0.559	0.570	0.581	0.591	0.601	0.612	0.622	0.633	0.643	0.653	0.663	0.674	0.684	0.694	0.704	
30										0.484	0.495	0.506	0.517	0.528	0.539	0.550	0.560	0.571	0.582	0.592	0.602	0.613	0.623	0.634	0.644	0.654	0.664	0.675	0.685	0.695	0.705	
32										0.486	0.497	0.508	0.519	0.530	0.540	0.551	0.561	0.572	0.583	0.593	0.603	0.614	0.624	0.635	0.645	0.655	0.665	0.676	0.686	0.696	0.706	
34										0.488	0.499	0.509	0.520	0.531	0.542	0.553	0.563	0.574	0.584	0.595	0.605	0.615	0.626	0.636	0.646	0.656	0.666	0.677	0.687	0.697	0.707	
36										0.489	0.500	0.511	0.522	0.533	0.543	0.554	0.564	0.575	0.586	0.596	0.606	0.617	0.627	0.638	0.648	0.658	0.668	0.678	0.688	0.698	0.708	
38										0.491	0.502	0.512	0.523	0.534	0.545	0.556	0.566	0.577	0.587	0.598	0.608	0.618	0.629	0.639	0.649	0.659	0.669	0.679	0.689	0.699	0.709	
40									0.483	0.493	0.504	0.514	0.525	0.536	0.546	0.557	0.567	0.578	0.588	0.599	0.609	0.619	0.630	0.640	0.650	0.660	0.670	0.680	0.690	0.700	0.710	
42									0.485	0.495	0.506	0.516	0.527	0.537	0.547	0.558	0.568	0.579	0.589	0.600	0.610	0.620	0.631	0.641	0.651	0.661	0.671	0.681	0.691	0.701		
44									0.486	0.497	0.507	0.517	0.528	0.539	0.549	0.559	0.570	0.580	0.591	0.601	0.611	0.621	0.632	0.642	0.652	0.662	0.672	0.682	0.692	0.702		
46									0.488	0.498	0.509	0.519	0.530	0.540	0.550	0.561	0.571	0.582	0.592	0.603	0.613	0.623	0.633	0.643	0.653	0.663	0.673	0.683	0.693	0.703		
48									0.489	0.500	0.510	0.520	0.531	0.542	0.552	0.562	0.573	0.583	0.594	0.604	0.614	0.624	0.634	0.644	0.654	0.664	0.674	0.684	0.694	0.704		
50								0.480	0.491	0.502	0.512	0.522	0.533	0.543	0.553	0.563	0.574	0.584	0.595	0.605	0.615	0.625	0.635	0.645	0.655	0.665	0.675	0.685	0.695	0.705		
52								0.482	0.493	0.504	0.514	0.524	0.534	0.544	0.554	0.564	0.575	0.585	0.596	0.606	0.616	0.626	0.636	0.646	0.656	0.666	0.676	0.686	0.696	0.706		
54								0.484	0.494	0.505	0.515	0.525	0.536	0.546	0.556	0.566	0.576	0.586	0.597	0.607	0.617	0.627	0.637	0.647	0.657	0.667	0.677	0.687	0.697	0.707		
56								0.486	0.496	0.507	0.517	0.527	0.537	0.547	0.557	0.567	0.578	0.588	0.598	0.608	0.618	0.628	0.638	0.648	0.658	0.668	0.678	0.688	0.698	0.708		
58								0.488	0.498	0.508	0.518	0.529	0.539	0.549	0.559	0.569	0.579	0.589	0.599	0.609	0.619	0.629	0.639	0.649	0.659	0.669	0.679	0.689	0.699	0.709		
60							0.480	0.490	0.500	0.510	0.520	0.530	0.540	0.550	0.560	0.570	0.580	0.590	0.600	0.610	0.620	0.630	0.640	0.650	0.660	0.670	0.680	0.690	0.700	0.710		
62							0.482	0.492	0.502	0.512	0.522	0.532	0.541	0.551	0.561	0.571	0.581	0.591	0.601	0.611	0.621	0.631	0.641	0.651	0.661	0.671	0.681	0.691	0.701			
64							0.484	0.494	0.504	0.513	0.523	0.533	0.543	0.553	0.563	0.573	0.582	0.592	0.602	0.612	0.622	0.632	0.642	0.652	0.662	0.672	0.682	0.692	0.702			
66							0.485	0.495	0.505	0.515	0.525	0.535	0.544	0.554	0.564	0.574	0.584	0.594	0.604	0.614	0.624	0.634	0.644	0.654	0.663	0.673	0.683	0.693	0.703			
68							0.487	0.497	0.507	0.517	0.526	0.536	0.546	0.556	0.566	0.576	0.585	0.595	0.605	0.615	0.625	0.635	0.645	0.655	0.664	0.674	0.684	0.694	0.704			
70						0.479	0.489	0.499	0.509	0.518	0.528	0.538	0.547	0.557	0.567	0.577	0.586	0.596	0.606	0.616	0.626	0.636	0.646	0.656	0.665	0.675	0.685	0.695	0.705			
72						0.481	0.491	0.501	0.511	0.520	0.529	0.539	0.548	0.558	0.568	0.578	0.587	0.597	0.607	0.617	0.627	0.637	0.647	0.657	0.666	0.676	0.686	0.696	0.706			
74						0.483	0.493	0.502	0.512	0.521	0.531	0.541	0.550	0.560	0.569	0.579	0.589	0.598	0.608	0.618	0.628	0.638	0.648	0.658	0.667	0.677	0.687	0.697	0.707			
76						0.484	0.494	0.504	0.513	0.523	0.532	0.542	0.551	0.561	0.571	0.581	0.590	0.600	0.610	0.620	0.629	0.639	0.649	0.659	0.668	0.678	0.688	0.698	0.706			
78						0.486	0.496	0.505	0.515	0.524	0.534	0.544	0.553	0.563	0.572	0.582	0.592	0.601	0.611	0.621	0.630	0.640	0.650	0.660	0.669	0.679	0.689	0.699	0.709			
80					0.479	0.488	0.498	0.507	0.517	0.526	0.535	0.545	0.554	0.564	0.573	0.583	0.593	0.602	0.612	0.622	0.631	0.641	0.651	0.661	0.670	0.680	0.690	0.700	0.710			
82					0.481	0.490	0.500	0.509	0.519	0.528	0.537	0.546	0.555	0.565	0.574	0.584	0.594	0.603	0.613	0.623	0.632	0.642	0.652	0.662	0.671	0.681	0.691	0.701				
84					0.483	0.492	0.501	0.510	0.520	0.529	0.538	0.548	0.557	0.567	0.576	0.585	0.595	0.604	0.614	0.624	0.633	0.643	0.653	0.663	0.672	0.682	0.692	0.702				
86					0.484	0.493	0.503	0.512	0.521	0.531	0.540	0.549	0.558	0.568	0.577	0.587	0.597	0.606	0.616	0.625	0.635	0.644	0.654	0.664	0.673	0.683	0.693	0.703				
88					0.486	0.495	0.504	0.513	0.523	0.532	0.541	0.551	0.560	0.569	0.579	0.588	0.598	0.607	0.617	0.626	0.636	0.645	0.655	0.665	0.674	0.684	0.694	0.704				
90				0.479	0.488	0.497	0.506	0.515	0.524	0.534	0.543	0.552	0.561	0.570	0.580	0.589	0.599	0.608	0.618	0.627	0.637	0.646	0.656	0.666	0.675	0.685	0.695	0.705				
92				0.481	0.490	0.499	0.508	0.517	0.526	0.535	0.544	0.553	0.562	0.572	0.581	0.590	0.600	0.609	0.619	0.628	0.638	0.647	0.657	0.667	0.676	0.686	0.696	0.706				
94				0.483	0.492	0.500	0.509	0.518	0.528	0.537	0.545	0.554	0.563	0.573	0.582	0.591	0.601	0.610	0.620	0.629	0.639	0.648	0.658	0.668	0.677	0.687	0.697	0.707				
96				0.484	0.493	0.502	0.511	0.520	0.529	0.538	0.547	0.556	0.565	0.574	0.584	0.593	0.602	0.612	0.621	0.630	0.640	0.649	0.659	0.669	0.678	0.688	0.698	0.708				
98				0.486	0.495	0.503	0.512	0.521	0.531	0.540	0.548	0.557	0.566	0.575	0.585	0.594	0.603	0.613	0.622	0.631	0.641	0.650	0.660	0.670	0.679	0.689	0.699	0.709				
100			0.480	0.488	0.497	0.505	0.514	0.523	0.532	0.541	0.549	0.558	0.567	0.577	0.586	0.595	0.604	0.614	0.623	0.632	0.642	0.651	0.661	0.671	0.680	0.690	0.700	0.710				
105			0.485	0.493	0.502	0.510	0.518	0.527	0.535	0.544	0.553	0.562	0.571	0.580	0.589	0.598																
110		0.481	0.489	0.497	0.506	0.514	0.522	0.530	0.539	0.548	0.557	0.565	0.574	0.583	0.592																
115		0.485	0.493	0.501	0.510	0.518	0.526	0.534	0.543	0.551	0.560	0.568	0.577	0.586	0.595																
120	0.482	0.489	0.497	0.505	0.513	0.521	0.529	0.538	0.546	0.554	0.563	0.571	0.580	0.589	0.598																
125	0.486	0.494	0.502	0.509	0.517	0.525	0.533	0.541	0.550	0.558	0.566	0.574	0.583	0.592																	
130	0.491	0.498	0.506	0.514	0.521	0.529	0.537	0.545	0.553	0.561	0.569	0.577	0.586	0.595																	
135	0.495	0.502	0.510	0.517	0.525	0.533	0.541	0.549	0.557	0.565	0.573	0.581	0.589	0.598																	
140	0.499	0.506	0.514	0.521	0.529	0.536	0.544	0.552	0.560	0.568	0.576	0.584	0.592	0.601																	

Table 1. Illustration for Use. Given the specific gravity (t/60) 0.620 at 26° F. The specific gravity 60/60 will be found by moving down the column headed 0.620 to intersect with the horizontal lines from 26° F. The specific gravity 60/60 is found to be 0.600.

Natural Gasoline Association of America.

N.G.A.A. VOLUME CORRECTION FACTORS (1942)

Observed Temperature Degrees Fahrenheit	SPECIFIC GRAVITIES AT 60° F./60° F.																									
	0.500	Propane 0.5079	0.510	0.520	0.530	0.540	0.550	0.560	iso-Butane 0.5631	0.570	0.580	n-Butane 0.5844	0.590	0.600	0.610	0.620	iso-Pentane 0.6246	0.630	n-Pentane 0.6310	0.640	0.650	0.660	0.670	0.680	0.690	0.700
	VOLUME CORRECTION FACTORS																									
—50	1.160	1.155	1.153	1.146	1.140	1.133	1.127	1.122	1.120	1.116	1.111	1.108	1.106	1.102												
—45	1.153	1.148	1.146	1.140	1.134	1.128	1.122	1.117	1.115	1.111	1.106	1.103	1.101	1.097												
—40	1.147	1.142	1.140	1.134	1.128	1.122	1.117	1.111	1.110	1.106	1.101	1.099	1.097	1.093												
—35	1.140	1.135	1.134	1.128	1.122	1.116	1.112	1.106	1.105	1.101	1.096	1.094	1.092	1.088												
—30	1.134	1.129	1.128	1.122	1.116	1.111	1.106	1.101	1.100	1.096	1.092	1.090	1.088	1.084												
—25	1.127	1.122	1.121	1.115	1.110	1.105	1.100	1.095	1.094	1.091	1.087	1.085	1.083	1.080												
—20	1.120	1.115	1.114	1.108	1.104	1.099	1.095	1.090	1.089	1.086	1.082	1.080	1.079	1.076												
—15	1.112	1.109	1.107	1.102	1.097	1.093	1.089	1.084	1.083	1.080	1.077	1.075	1.074	1.071												
—10	1.105	1.102	1.100	1.095	1.091	1.087	1.083	1.079	1.078	1.075	1.072	1.071	1.069	1.066												
— 5	1.098	1.094	1.094	1.089	1.085	1.081	1.077	1.074	1.073	1.070	1.067	1.066	1.065	1.062												
0	1.092	1.088	1.088	1.084	1.080	1.076	1.073	1.069	1.068	1.066	1.063	1.062	1.061	1.058	1.055	1.053	1.052	1.051	1.051	1.050	1.048	1.046	1.045	1.044	1.043	1.042
2	1.089	1.086	1.085	1.081	1.077	1.074	1.070	1.067	1.066	1.064	1.061	1.060	1.059	1.056	1.053	1.051	1.050	1.049	1.049	1.048	1.046	1.045	1.044	1.043	1.042	1.041
4	1.086	1.083	1.082	1.079	1.075	1.071	1.068	1.065	1.064	1.062	1.059	1.058	1.057	1.054	1.051	1.049	1.049	1.048	1.048	1.047	1.045	1.043	1.042	1.041	1.041	1.039
6	1.084	1.080	1.080	1.076	1.072	1.069	1.065	1.062	1.061	1.059	1.057	1.055	1.054	1.052	1.050	1.048	1.047	1.046	1.046	1.045	1.043	1.042	1.041	1.040	1.039	1.038
8	1.081	1.078	1.077	1.074	1.070	1.066	1.063	1.060	1.059	1.057	1.055	1.053	1.052	1.050	1.048	1.046	1.045	1.045	1.045	1.044	1.042	1.040	1.039	1.038	1.037	1.036
10	1.078	1.075	1.074	1.071	1.067	1.064	1.061	1.058	1.057	1.055	1.053	1.051	1.050	1.048	1.046	1.044	1.044	1.043	1.043	1.042	1.040	1.039	1.038	1.037	1.036	1.035
12	1.075	1.072	1.071	1.068	1.064	1.061	1.059	1.056	1.055	1.053	1.051	1.049	1.048	1.046	1.044	1.042	1.042	1.041	1.041	1.040	1.038	1.037	1.036	1.035	1.035	1.034
14	1.072	1.070	1.069	1.066	1.062	1.059	1.056	1.053	1.053	1.051	1.049	1.047	1.046	1.044	1.042	1.041	1.040	1.039	1.039	1.038	1.037	1.036	1.035	1.034	1.033	1.032
16	1.070	1.067	1.066	1.063	1.060	1.056	1.054	1.051	1.050	1.048	1.046	1.045	1.044	1.043	1.041	1.039	1.039	1.038	1.038	1.036	1.036	1.034	1.033	1.032	1.032	1.031
18	1.067	1.065	1.064	1.061	1.057	1.054	1.051	1.049	1.048	1.046	1.044	1.043	1.042	1.041	1.039	1.038	1.037	1.036	1.036	1.035	1.034	1.033	1.032	1.031	1.030	1.029
20	1.064	1.062	1.061	1.058	1.054	1.051	1.049	1.046	1.046	1.044	1.042	1.041	1.040	1.039	1.037	1.036	1.035	1.034	1.034	1.033	1.032	1.031	1.030	1.029	1.029	1.028
22	1.061	1.059	1.058	1.055	1.052	1.049	1.046	1.044	1.044	1.042	1.040	1.039	1.038	1.036	1.035	1.034	1.033	1.032	1.032	1.031	1.030	1.030	1.029	1.028	1.028	1.027
24	1.058	1.056	1.055	1.052	1.049	1.046	1.044	1.042	1.042	1.040	1.038	1.037	1.036	1.034	1.033	1.032	1.032	1.031	1.031	1.030	1.029	1.028	1.027	1.026	1.026	1.025
26	1.055	1.053	1.052	1.049	1.047	1.044	1.042	1.039	1.039	1.037	1.036	1.036	1.034	1.033	1.032	1.031	1.030	1.029	1.029	1.028	1.027	1.027	1.026	1.025	1.024	1.024
28	1.052	1.050	1.049	1.047	1.044	1.041	1.039	1.037	1.037	1.035	1.034	1.034	1.032	1.031	1.030	1.029	1.028	1.028	1.028	1.027	1.026	1.025	1.024	1.023	1.023	1.022
30	1.049	1.047	1.046	1.044	1.041	1.039	1.037	1.035	1.035	1.033	1.032	1.032	1.030	1.029	1.028	1.027	1.027	1.026	1.026	1.025	1.024	1.024	1.023	1.022	1.022	1.021
32	1.046	1.044	1.043	1.041	1.038	1.036	1.035	1.033	1.033	1.031	1.030	1.030	1.028	1.027	1.026	1.025	1.025	1.024	1.024	1.023	1.022	1.022	1.021	1.021	1.020	1.020
34	1.043	1.041	1.040	1.038	1.036	1.034	1.032	1.031	1.030	1.029	1.028	1.028	1.026	1.025	1.024	1.023	1.023	1.022	1.022	1.022	1.021	1.021	1.020	1.019	1.019	1.018
36	1.039	1.038	1.037	1.035	1.033	1.031	1.030	1.028	1.028	1.027	1.025	1.025	1.024	1.023	1.023	1.022	1.021	1.021	1.021	1.020	1.019	1.019	1.018	1.018	1.017	1.017
38	1.036	1.035	1.034	1.032	1.031	1.029	1.027	1.026	1.025	1.025	1.023	1.023	1.022	1.021	1.021	1.020	1.020	1.019	1.019	1.019	1.018	1.018	1.017	1.016	1.016	1.015
40	1.033	1.032	1.031	1.029	1.028	1.026	1.025	1.024	1.023	1.023	1.021	1.021	1.020	1.019	1.019	1.018	1.018	1.017	1.017	1.017	1.016	1.016	1.015	1.015	1.014	1.014
42	1.030	1.029	1.028	1.027	1.025	1.024	1.023	1.022	1.021	1.021	1.019	1.019	1.018	1.018	1.017	1.016	1.016	1.015	1.015	1.015	1.014	1.014	1.013	1.013	1.013	1.013
44	1.027	1.026	1.025	1.023	1.022	1.021	1.020	1.019	1.019	1.018	1.017	1.017	1.016	1.016	1.015	1.014	1.014	1.014	1.014	1.013	1.013	1.013	1.012	1.012	1.011	1.011
46	1.023	1.022	1.022	1.021	1.020	1.018	1.018	1.017	1.016	1.016	1.015	1.015	1.014	1.014	1.013	1.013	1.013	1.012	1.012	1.012	1.011	1.011	1.010	1.010	1.010	1.010
48	1.020	1.019	1.019	1.018	1.017	1.016	1.015	1.014	1.014	1.013	1.013	1.013	1.012	1.012	1.011	1.011	1.011	1.011	1.011	1.010	1.010	1.010	1.009	1.009	1.008	1.008
50	1.017	1.016	1.016	1.015	1.014	1.013	1.013	1.012	1.012	1.011	1.011	1.011	1.010	1.010	1.009	1.009	1.009	1.009	1.009	1.008	1.008	1.008	1.007	1.007	1.007	1.007
52	1.014	1.013	1.012	1.012	1.011	1.010	1.010	1.009	1.009	1.009	1.009	1.009	1.008	1.008	1.007	1.007	1.007	1.007	1.007	1.007	1.006	1.006	1.006	1.006	1.006	1.005
54	1.010	1.010	1.009	1.009	1.008	1.008	1.007	1.007	1.007	1.007	1.006	1.006	1.006	1.006	1.006	1.005	1.005	1.005	1.005	1.005	1.005	1.004	1.004	1.004	1.004	1.004
56	1.007	1.007	1.006	1.006	1.005	1.005	1.005	1.005	1.005	1.005	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003
58	1.003	1.003	1.003	1.003	1.003	1.003	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.001	1.001	1.001	1.001
60	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
62	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.999	0.999	0.999
64	0.993	0.993	0.994	0.994	0.994	0.994	0.995	0.995	0.995	0.995	0.996	0.996	0.996	0.996	0.996	0.996	0.996	0.996	0.996	0.997	0.997	0.997	0.997	0.997	0.997	0.997
66	0.990	0.990	0.990	0.990	0.991	0.992	0.992	0.993	0.993	0.993	0.993	0.993	0.994	0.994	0.994	0.995	0.995	0.995	0.995	0.995	0.995	0.995	0.996	0.996	0.996	0.996
68	0.986	0.986	0.987	0.987	0.988	0.989	0.990	0.990	0.990	0.990	0.991	0.991	0.991	0.992	0.992	0.993	0.993	0.933	0.993	0.994	0.994	0.994	0.994	0.994	0.994	0.994
70	0.983	0.983	0.984	0.984	0.985	0.986	0.987	0.988	0.988	0.988	0.989	0.989	0.989	0.990	0.990	0.991	0.991	0.991	0.991	0.992	0.992	0.992	0.992	0.993	0.993	0.993
72	0.979	0.980	0.981	0.981	0.982	0.983	0.984	0.985	0.986	0.986	0.987	0.987	0.987	0.988	0.988	0.989	0.989	0.989	0.989	0.990	0.990	0.990	0.991	0.991	0.992	0.992
74	0.976	0.976	0.977	0.978	0.980	0.980	0.982	0.983	0.983	0.984	0.985	0.985	0.985	0.986	0.986	0.987	0.987	0.987	0.987	0.988	0.988	0.989	0.989	0.990	0.990	0.990
76	0.972	0.973	0.974	0.975	0.977	0.978	0.979	0.980	0.981	0.981	0.982	0.982	0.983	0.984	0.985	0.986	0.986	0.986	0.986	0.987	0.987	0.987	0.988	0.988	0.989	0.989
78	0.969	0.970	0.970	0.972	0.974	0.975	0.977	0.978	0.978	0.979	0.980	0.980	0.981	0.982	0.983	0.984	0.984	0.984	0.984	0.985	0.986	0.986	0.986	0.987	0.987	0.987
80	0.965	0.967	0.967	0.969	0.971	0.972	0.974	0.975	0.976	0.977	0.978	0.978	0.979	0.980	0.981	0.982	0.982	0.982	0.982	0.983	0.984	0.984	0.985	0.985	0.986	0.986
82	0.961	0.963	0.963	0.966	0.968	0.969	0.971	0.972	0.973	0.974	0.976	0.976	0.977	0.978	0.979	0.980	0.980	0.980	0.980	0.981	0.982	0.983	0.983	0.984	0.984	0.985
84	0.957	0.959	0.960	0.962	0.965	0.966	0.968	0.970	0.971	0.972	0.974	0.974	0.975	0.976	0.977	0.978	0.979	0.979	0.979	0.980	0.981	0.981	0.982	0.982	0.983	0.983
86	0.954	0.956	0.956	0.959	0.961	0.964	0.966	0.967	0.968	0.969	0.971	0.971	0.972	0.973	0.975	0.976	0.977	0.977	0.977	0.978	0.979	0.980	0.980	0.981	0.981	0.982
88	0.950	0.952	0.953	0.955	0.958	0.961	0.963	0.965	0.966	0.967	0.969	0.969	0.970	0.971	0.973	0.974	0.975	0.976	0.976	0.977	0.978	0.978	0.979	0.979	0.980	0.980
90	0.946	0.949	0.949	0.952	0.955	0.958	0.960	0.962	0.963	0.964	0.967	0.967	0.968	0.969	0.971	0.972	0.973	0.974	0.974	0.975	0.976	0.977	0.977	0.978	0.978	0.979
92	0.942	0.945	0.946	0.949	0.952	0.955	0.957	0.959	0.960	0.962	0.964	0.965	0.966	0.967	0.969	0.970	0.971	0.972	0.972	0.973	0.974	0.975	0.975	0.976	0.977	0.977
94	0.938	0.941	0.942	0.946	0.949	0.952	0.954	0.957	0.958	0.959	0.962	0.962	0.964	0.965	0.967	0.968	0.969	0.970	0.970	0.971	0.972	0.973	0.974	0.975	0.975	0.976
96	0.935	0.938	0.939	0.942	0.946	0.949	0.952	0.954	0.955	0.957	0.959	0.960	0.961	0.963	0.965	0.966	0.967	0.968	0.968	0.970	0.971	0.972	0.972	0.973	0.974	0.975
98	0.931	0.934	0.935	0.939	0.943	0.946	0.949	0.952	0.953	0.954	0.957	0.957	0.959	0.961	0.963	0.964	0.965	0.966	0.966	0.968	0.969	0.970	0.971	0.972	0.972	0.973
100	0.927	0.930	0.932	0.936	0.940	0.943	0.946	0.949	0.950	0.952	0.954	0.955	0.957	0.959	0.961	0.962	0.963	0.964	0.964	0.966	0.967	0.968	0.969	0.970	0.971	0.972
105	0.917	0.920	0.923	0.927	0.931	0.935	0.939	0.943	0.943	0.946	0.949	0.949	0.951	0.954												
110	0.907	0.911	0.913	0.918	0.923	0.927	0.932	0.936	0.937	0.939	0.943	0.944	0.946	0.949												
115	0.897	0.902	0.904	0.909	0.915	0.920	0.925	0.930	0.930	0.933	0.937	0.938	0.940	0.944												
120	0.887	0.892	0.894	0.900	0.907	0.912	0.918	0.923	0.924	0.927	0.931	0.932	0.934	0.938												
125	0.876	0.881	0.884	0.890	0.898	0.903	0.909	0.916	0.916	0.920	0.925	0.927	0.928	0.933												
130	0.865	0.871	0.873	0.880	0.888	0.895	0.901	0.908	0.909	0.913	0.918	0.921	0.923	0.927												
135	0.854	0.861	0.863	0.871	0.879	0.887	0.894	0.901	0.902	0.907	0.912	0.914	0.916	0.921												
140	0.842	0.850	0.852	0.861	0.870	0.879	0.886	0.893	0.895	0.900	0.905	0.907	0.910	0.915												

Table 2. Illustration for Use. Given the specific (60/60) 0.600 and temperature of measurement of 26° F. The volume correction factor to convert the volume at the measured temperature of 26° F. to volume at 6° F. is found by moving down the column headed 0.600 to intersect with the horizontal line from 26° F. The volume correction factor is 1.033.

Natural Gasoline Association of America.

VAPOR PRESSURES OF PROPANE, BUTANE AND ISOBUTANE

Temp.	PROPANE		BUTANE		ISOBUTANE		Temp.
	PRESSURE—LBS. PER SQ. IN.						
Deg. F.	Absolute	Gauge	Absolute	Gauge	Absolute	Gauge	Deg. F.
—75	6.37	*17.0					—75
—70	7.37	*14.9					—70
—65	8.48	*12.7					—65
—60	9.72	*10.1					—60
—55	11.1	* 7.3					—55
—50	12.6	* 4.3					—50
—45	14.4	* 0.6					—45
—40	16.2	1.5					—40
—35	18.1	3.4					—35
—30	20.3	5.6					—30
—25	22.7	8.0					—25
—20	25.4	10.7			7.50	*14.6	—20
—15	28.3	13.6			8.30	*13.0	—15
—10	31 4	16.7			9.28	*11.0	—10
— 5	34.7	20.0			10.4	* 8.8	— 5
0	38.2	23.5	7.3	*15.0	11.6	* 6.3	0
5	41.9	27.2	8.2	*13.2	13.1	* 3.3	5
10	46.0	31.3	9.2	*11.1	14.6	* 0.2	10
15	50.6	35.9	10.4	* 8.8	16.3	1.6	15
20	55.5	40.8	11.6	* 6.3	18.2	3.5	20
25	60.9	46.2	13.0	* 3.6	20.2	5.5	25
30	66.3	51.6	14.4	* 0.6	22.3	7.6	30
35	72.0	57.3	16.0	1.3	24.6	9.9	35
40	78.0	63.3	17.7	3.0	26.9	12.2	40
45	84.6	69.9	19.6	4.9	29.5	14.8	45
50	91.8	77.1	21.6	6.9	32.5	17.8	50
55	99.3	84.6	23.8	9.1	35.5	20.8	55
60	107.1	92.4	26.3	11.6	38.7	24.0	60
65	115.4	100.7	28.9	14.2	42.2	27.5	65
70	124.0	109.3	31.6	16.9	45.8	31.1	70
75	133.2	118.5	34.5	19.8	49.7	35.0	75
80	142.8	128.1	37.6	22.9	53.9	39.2	80
85	153.1	138.4	40.9	26.2	58.6	43.9	85
90	164.0	149.0	44.5	29.8	63.3	48.6	90
95	175.0	160.0	48.2	33.5	68.4	53.7	95
100	187.0	172.0	52.2	37.5	73.7	59.0	100
105	200.0	185.0	56.4	41.7	79.3	64.6	105
110	212.0	197.0	60.8	46.1	85.1	70.4	110
115	226.0	211.0	65.6	50.9	91.4	76.7	115
120	240.0	225.0	70.8	56.1	98.0	83.3	120
125	254.0	239.0	76.0	61.3	104.8	90.1	125
130	272.0	257.3	81.4	66.7	112.0	97.3	130
135	288.0	273.3	87.0	72.3	119.3	104.6	135
140	305.0	290.3	92.6	77.9	126.8	112.1	140
145			100.0	85.3	136.0	121.3	145
150			108.0	93.7	145.0	130.3	150
155			115.0	100.3	155.0	140.3	155
160			122.0	107.3	165.0	150.3	160
165			130.0	115.3	175.0	160.3	165
170			140.0	125.3	186.0	171.3	170
175			150.0	135.3	198.0	183.3	175
180			160.0	145.3	210.0	195.3	180

* Inches of mercury below one standard atmosphere (29.92 in.).

Dana, Jenkins, Burdick and Timm, Refrigerating Engineering, June 1926.

VAPORIZATION OF LIQUID IN PROPANE TANKS

Many times the question arises, especially on peak shaving installations using propane: Is it necessary to turn on the vaporizers?

For comparatively short-time peak shaving it is possible to obtain sufficient vapor from the storage tank itself without passing liquid propane through the vaporizer.

It is a well-known fact that the vapor pressure of a gas bears a direct relationship to the temperature and that the latent heat of vaporization is the amount of heat required to convert a liquid to a gas (also known as boiling point) at given pressure and temperature conditions; and further:

"The rate of heat transfer has been set at 2 Btu per hour per degrees temperature differential per sq. ft. of tank area in contact with the liquid."

Knowing these basic gas laws, we can evolve a formula to determine the amount of liquid propane vaporized in a standard storage tank in one hour.

$$\frac{2 \text{ Btu} \times (T_1 - T_2) \times \text{wetted area in sq ft}}{\text{LH per gal.}} = \text{Gal/hr}$$

T_1 = Outside air temperature in degrees F

T_2 = Ultimate temperature in degrees F of propane liquid at minimum required pressure condition

LH: per gal. = Latent Heat of vaporization (in Btu's) to vaporize one gallon of propane at T_2

As an example, let us assume that a 30,000 (wc) tank is half full of propane (wetted area = 1014 sq. ft.) and the outside air temperature is 80° F and the required vapor pressure can be as low as 10 psi gauge. How many gallons per hour is available due to the vaporization of liquid in storage tank?

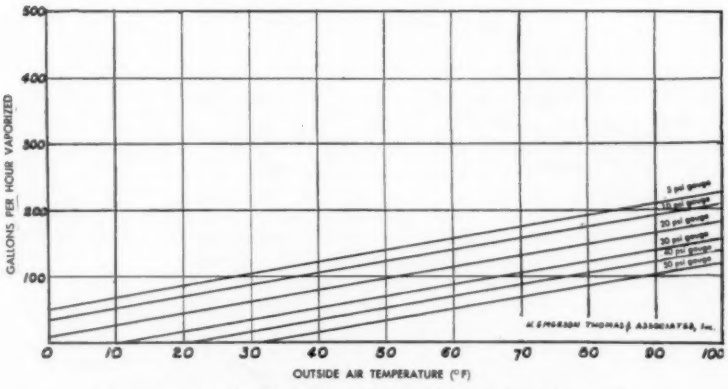
Referring to standard table of thermodynamic properties of propane; temperature at 10 psi ga is —20° F; and the latent heat of vaporization is 750 Btu per gal.

From the above formula—

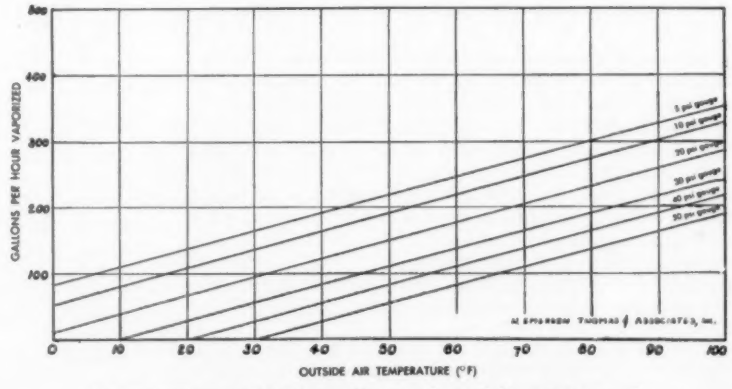
$$\frac{2 \text{ Btu} \times (80°\text{F} - (-20°\text{F})) \times 1014 \text{ sq ft}}{750 \text{ Btu per gal}} = 271 \text{ gal}$$

With the above conditions, we therefore can vaporize 271 gallons per hour without recourse to a vaporizer.

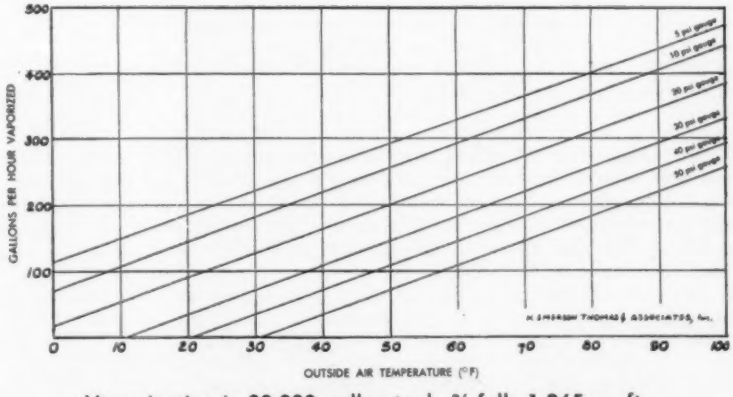
If this draw is maintained over a long period of time on a humid day, the surface of the tank in contact with the liquid will become frosted due to the refrigeration action of the liquid vaporized and the effective temperature differential will be substantially reduced.



Vaporization in 30,000 gallon tank, ¼ full—662 sq. ft.



Vaporization in 30,000 gallon tank, ½ full—1,014 sq. ft.



Vaporization in 30,000 gallon tank, ¾ full—1,365 sq. ft.

But in this discussion we are considering only comparatively short usages so as to obtain maximum vaporization.

Using the basic formula, graphs have been plotted which give available gallons per hour vaporized at various outside temperatures and pressure requirements of vapor and at varying filling heights in a 30,000 gallon (wc) tank containing commercial grade propane.

Referring to the graphs it is possible to decide when the vaporizer equipment will be required to obtain the necessary gas load.

Art E. Wastie, chief engineer, H. Emerson Thomas and Associates, Westfield, N. J.

STORAGE AND HANDLING OF LIQUEFIED PETROLEUM GASES

General. The term "liquefied petroleum gases" as used in these standards shall mean and include any material which is composed predominantly of any of the following hydrocarbons, or mixtures of them; propane, propylene, butanes (normal butane or isobutane), and butylenes.

Under moderate pressure the gases liquefy, but upon relief of the pressure are readily converted into the gaseous phase. Advantage of this characteristic is taken by the industry, and for convenience the gases are shipped and stored under pressure as liquids. When in the gaseous state, these gases present a hazard comparable to any flammable natural or manufactured gas, except that being heavier than air, ventilation requires added attention. The range of combustibility is considerably narrower than that of manufactured gas.

At atmospheric pressure and below 31° F. butane is a liquid. Propane is a liquid at atmospheric pressure at temperatures below minus 44° F. and normally does not present a flammable liquid hazard.

Rapid vaporization takes place at temperatures above the boiling points (butane about 30° F.; propane about minus 44° F.). Normal storage of these gases is as a liquid under pressure.

The following standards, here given in part, are intended to apply to the design, construction, location, installation, and operation of liquefied petroleum gas systems. These standards do not apply to marine terminals, pipe line and similar large volume terminals, natural gasoline plants, refineries, tank farms, or to chemical and utility gas manufacturing plants where specific approval of construction and installation plans is obtained from regulatory bodies having jurisdiction, provided such approval is based on substantially equivalent requirements.

Odorizing Gases. All liquefied petroleum gases shall be effectively odorized by an approved agent of such character as to indicate postively, by a distinctive odor, the presence of gas down to concentration in air of not over one-fifth the lower limit of combustibility.

NOTE: The lower limits of combustibility of the more commonly used liquefied petroleum gases are: Propane, 2.15 per cent; Butane, 1.55 per cent. These figures represent volumetric percentages of gas-air mixtures in each case.

Location of Containers and Regulating Equipment. Containers and first stage regulating equipment shall be located outside of buildings other than those especially provided for this purpose. Except as herein provided, each individual container shall be located with respect to nearest important building or group of buildings or line of adjoining property which may be built upon in accordance with the following table:

Water Capacity Per Container	Minimum Distance		Dist. Bet. Aboveground Containers
	Underground	Aboveground	
Less than 125 gallons	10 feet	None	None
125 to 500 gallons	10 feet	10 feet	3 feet
501 to 1,200 gallons	25 feet	25 feet	3 feet
Over 1,200 gallons	50 feet	50 feet	5 feet

In cases of bulk storage in heavily populated or congested areas, the inspection department having jurisdiction shall determine restrictions of individual container capacity, total storage, and distance to line of adjoining property which may be built on and other reasonable protective methods.

In industrial installations involving containers of 150,000 gallons aggregate capacity or more, where serious mutual exposures between the container and adjacent properties prevail, the enforcing authority having jurisdiction may require fire walls designed and constructed in accordance with good engineering practice.

In the case of buildings devoted exclusively to gas manufacturing and distributing operations the above distances may be reduced provided that in no case shall containers of capacity exceeding 500 gallons be located closer than 10 ft. to such gas manufacturing and distributing buildings.

Readily ignitable material such as weeds and long dry grass shall be removed within ten feet of any container.

Container Valves and Accessories, Filler Pipes and Discharge Pipes. All shut-off valves and accessory equipment (liquid or gas) shall be approved for use with liquefied petroleum gas, and designed for not less than the maximum pressure to which they may be subjected. Valves which may be subject to container pressure shall have a rated working pressure of at least 250 pounds per square inch gauge.

All connections to containers, except safety relief connections and gauging devices shall have shut-off valves located as close to the container as practicable.

The filling pipe inlet terminal shall not be located inside a building. Such terminals shall be located not less than 10 feet from any building and preferably not less than 5 feet from any driveway, and shall be located in a protective housing built for the purpose.

The filling connection shall be fitted with an approved combination back-pressure check valve and excess flow valve; a double or 2 back-pressure check valves; or a positive shut-off valve, in conjunction with either an internal back-pressure valve or an internal excess flow valve.

All liquid and vapor connections to containers except filling pipes and safety relief connections shall be equipped with approved automatic excess flow valves, except that no excess flow valve is required in the withdrawal service line, provided that:

1. The discharge from the service outlet is controlled by a suitable manually operated shut-off valve:
   (a) threaded directly into the service outlet of the container,
   (b) or which is an integral part of a substantial fitting threaded into or on the service outlet of the container,
   (c) or threaded directly into a substantial fitting threaded into or on the service outlet of the container.
2. The shut-off valve is equipped with an attached handwheel or the equivalent.
3. The controlling orifice between the contents of the container and the outlet of the shut-off valves does not exceed 5/16 in. in diameter for vapor withdrawal systems and ⅛ in. in diameter for liquid withdrawal systems.
4. An approved pressure-reducing regulator is directly attached to the outlet of the shut-off valve and is rigidly supported, or that an approved pressure-reducing regulator is attached to the outlet of the shut-off valve by means of a suitable flexible connection not longer than 20 in. and is rigidly supported.
5. Such systems' total water capacity does not exceed 1,200 U. S. gallons.

All inlet and outlet connections except safety relief valves, liquid level gauging devices and pressure gauges on containers of 1,200 gallons water capacity, or more, and on any container used to supply fuel directly to an internal combustion engine, shall be labeled to designate whether they communicate with vapor or liquid space. Labels may be on valves.

Excess flow valves where required by these standards shall close automatically at those rated flows of vapor or liquid as specified by the manufacturer. The connections or line including valves, fittings, etc., being protected by an excess flow valve shall have a greater capacity than the rated flow of the excess flow valve.

Liquid level gauging devices which are so constructed that outward flow of container contents shall not exceed that passed by a

No. 54 drill size opening, need not be equipped with excess flow valves.

Openings from tank or through fittings attached directly on tank to which pressure gauge connection is made need not be equipped with excess flow valve if such openings are protected by not larger than No. 54 drill size opening.

Excess flow and back pressure check valves where required by these standards shall be located inside of the container or at a point outside where the line enters the container; in the latter case, installation shall be made in such manner that any undue strain beyond the excess flow or back pressure check valve will not cause breakage between the container and such valve.

Excess flow valves may be designed with a by-pass, not to exceed a 60 drill size opening to allow equalization of pressures.

Piping, Tubing, and Fittings. Piping or tubing shall be wrought iron, steel, brass or copper pipe; or, except as hereinafter provided, seamless copper, brass, steel or other approved gas tubing. All piping or tubing shall be suitable for a working pressure of not less than 125 pounds per square inch. Copper tubing may be of the standard grade K or L. Aluminum tubing shall not be used in exterior locations or where it passes through masonry or plaster walls or insulation.

Pipe joints may be screwed, flanged, welded, brazed or soldered with a solder having a melting point of over 1000° F. Where fittings are used they shall have a working pressure of at least 125 pounds in systems where the operating pressure is 125 pounds per square inch or less. Extra heavy fittings shall be used for pressure exceeding 125 pounds per square inch or less. Cast iron fittings shall be prohibited. Joints on seamless copper, brass, steel, or non-ferrous gas tubing shall be made by means of approved gas tubing fittings or soldered with solders having a melting point exceeding 1000° F. Valve seat material, packing, gaskets, etc., shall be of such quality as to be resistant to the action of liquefied petroleum gas in the liquid phase.

Hose Specifications. Hose shall be fabricated of materials that are resistant to the action of liquefied petroleum gases.

Hose subject to container pressure shall be designed for a bursting pressure of not less than five times the pressure for which the container was designed. Hose connections when made shall be capable of withstanding a test pressure of twice the pressure for which the container is designed.

Filling Densities. The "filling density" is defined as the per cent ratio of the weight of the gas in a container to the weight of water the container will hold at 60° F. The filling densities for storage containers shall not exceed the ratios following:

MAXIMUM PERMITTED FILLING DENSITY

Specific Gravity at 60°	Aboveground Containers 0 to 1200 Gals.* Total Water Cap.	Aboveground Containers Over 1200 Gals. Total Water Cap.	Underground Containers All Capacities
.473—.480	38%	41%	42%
.481—.488	39	42	43
.489—.495	40	43	44
.496—.503	41	44	45
.504—.510	42	45	46
.511—.519	43	46	47
.520—.527	44	47	48
.528—.536	45	48	49
.537—.544	46	49	50
.545—.552	47	50	51
.553—.560	48	51	52
.561—.568	49	52	53
.569—.576	50	53	54
.577—.584	51	54	55
.585—.592	52	55	56
.593—.600	53	56	57
.601—.608	54	57	58
.609—.617	55	58	59
.618—.626	56	59	60
.627—.634	57	60	61

* Interstate Commerce Commission filling densities effective on the date of adoption of this standard.

Safety Devices. Every container and every vaporizer, whether heated by artificial means or not, shall be provided with one or more safety relief valves of spring-loaded or equivalent type. These valves shall be arranged to afford free vent to the outer air with discharge of not less than 5 ft. horizontally away from any opening into the building which is below such discharge. The area of the discharge shall be sufficient to prevent the building up of pressures in excess of 120% of the maximum permitted setting of the safety relief valves on the container and in accordance with the regulations of the National Board of Fire Underwriters, as contained in its Pamphlet No. 58. (Revised January, 1947.)

Container safety relief valves shall be set to start to discharge as follows, with relation to the container type:

Containers	Minimum	Maximum
A.S.M.E.-U-68, U-69	100%	125%
A.S.M.E.-U-200, U-201	90	100
A.P.I.-A.S.M.E.	80	100

Electrical Connections and Open Flames. In vaporizer or pump houses, in cylinder filling rooms and similar locations, all electrical installations shall be in strict accordance with the requirements of the National Electrical Code for Class I, Group D hazardous locations.

In vaporizer or pump houses, in cylinder filling rooms and similar locations, open flames or other sources of ignition shall not be permitted.

Design Working Pressure and Classification of Storage Containers. Storage containers shall be designed and classified as follows:

"Container Type"	For Gases with Vapor Pressure Not to Exceed Lbs. per Sq. In. Gauge at 100° F.	Minimum Design Working Pressure of Containers by: A.S.M.E. Code U-68 U-69	A.S.M.E. Code U-200 U-201	A.P.I.-A.S.M.E. Code
100	100	100 lb. Ga.	113 lb. Ga.	125 lb. Ga.
125	125	125 " "	141 " "	156 " "
150	150	150 " "	169 " "	187 " "
175	175	175 " "	197 " "	219 " "
200	200	200 " "	225 " "	250 " "

The shell or head thickness of any container shall not be less than 3/16 inch.

NOTE: Because of low soil temperature usually encountered, and the insulating effect of the earth, the average vapor pressure of products stored in underground containers will be materially lower than when stored aboveground. This reduction in actual operating pressure therefore provides a substantial corrosion allowance for these containers when installed underground.

Capacity of Liquid Containers. No liquid storage container shall exceed 30,000 standard U. S. gallons capacity.

Installation of Storage Containers. Containers installed aboveground (except "skid tanks") shall be provided with substantial masonry or non-combustible structural supports on firm masonry foundations.

Except as modified by the note, aboveground containers shall be supported as follows:

Horizontal containers shall be mounted on saddles and secured thereto in such a manner as to permit expansion and contraction. Every container shall be so supported as to prevent the concentration of excessive loads on the supporting portion of the shell. Structural metal supports may be employed when they are protected against fire in an approved manner. Suitable means of preventing corrosion shall be provided on that portion of the container in contact with the foundations or saddles.

NOTE: Containers of 1,200 gallons water capacity or less may be installed with non-fireproof ferrous metal supports if mounted on concrete pads or footings, and if the distance from the outside bottom of the container shell to the ground does not exceed 24 in.

(Information and data from publications of the National Board of Fire Underwriters: Pamphlet No. 58—Liquefied Petroleum Gases—March 1949. Pamphlet No. 59—Liquefied Petroleum Gases at Utility Gas Plants—March 1949.)

HEATING VALUE OF PETROLEUM OILS

CRUDE OILS, FUEL OILS AND KEROSENE

Gravity		Density	Total heat of combustion at constant volume, Q_v			Net heat of combustion at constant pressure, Q_p			Degrees A. P. I. at 60° F.
Degrees A. P. I. at 60° F.	Specific at 60°/60° F.	Pounds per gallon	Cal./g	Btu./lb.	Btu./gal.	Cal./g	Btu./lb.	Btu./gal.	
10	1. 0000	8. 337	10, 300	18, 540	154, 600	9, 740	17, 540	146, 200	**10**
11	. 9930	8. 279	10, 330	18, 590	153, 900	9, 770	17, 580	145, 600	11
12	. 9861	8. 221	10, 360	18, 640	153, 300	9, 790	17, 620	144, 900	12
13	. 9792	8. 164	10, 390	18, 690	152, 600	9, 810	17, 670	144, 200	13
14	. 9725	8. 108	10, 410	18, 740	152, 000	9, 840	17, 710	143, 600	14
15	. 9659	8. 053	10, 440	18, 790	151, 300	9, 860	17, 750	142, 900	**15**
16	. 9593	7. 998	10, 470	18, 840	150, 700	9, 880	17, 790	142, 300	16
17	. 9529	7. 944	10, 490	18, 890	150, 000	9, 900	17, 820	141, 600	17
18	. 9465	7. 891	10, 520	18, 930	149, 400	9, 920	17, 860	140, 900	18
19	. 9402	7. 839	10, 540	18, 980	148, 800	9, 940	17, 900	140, 300	19
20	. 9340	7. 787	10, 570	19, 020	148, 100	9, 960	17, 930	139, 600	**20**
21	. 9279	7. 736	10, 590	19, 060	147, 500	9, 980	17, 960	139, 000	21
22	. 9218	7. 686	10, 620	19, 110	146, 800	10, 000	18, 000	138, 300	22
23	. 9159	7. 636	10, 640	19, 150	146, 200	10, 020	18, 030	137, 700	23
24	. 9100	7. 587	10, 660	19, 190	145, 600	10, 040	18, 070	137, 100	24
25	. 9042	7. 538	10, 680	19, 230	145, 000	10, 050	18, 100	136, 400	**25**
26	. 8984	7. 490	10, 710	19, 270	144, 300	10, 070	18, 130	135, 800	26
27	. 8927	7. 443	10, 730	19, 310	143, 700	10, 090	18, 160	135, 200	27
28	. 8871	7. 396	10, 750	19, 350	143, 100	10, 110	18, 190	134, 600	28
29	. 8816	7. 350	10, 770	19, 380	142, 500	10, 120	18, 220	133, 900	29
30	. 8762	7. 305	10, 790	19, 420	141, 800	10, 140	18, 250	133, 300	**30**
31	. 8708	7. 260	10, 810	19, 450	141, 200	10, 150	18, 280	132, 700	31
32	. 8654	7. 215	10, 830	19, 490	140, 600	10, 170	18, 310	132, 100	32
33	. 8602	7. 171	10, 850	19, 520	140, 000	10, 180	18, 330	131, 500	33
34	. 8550	7. 128	10, 860	19, 560	139, 400	10, 200	18, 360	130, 900	34
35	. 8498	7. 085	10, 880	19, 590	138, 800	10, 210	18, 390	130, 300	**35**
36	. 8448	7. 043	10, 900	19, 620	138, 200	10, 230	18, 410	129, 700	36
37	. 8398	7. 001	10, 920	19, 650	137, 600	10, 240	18, 430	129, 100	37
38	. 8348	6. 960	10, 940	19, 680	137, 000	10, 260	18, 460	128, 500	38
39	. 8299	6. 920	10, 950	19, 720	136, 400	10, 270	18, 480	127, 900	39
40	. 8251	6. 879	10, 970	19, 750	135, 800	10, 280	18, 510	127, 300	**40**
41	. 8203	6. 839	10, 990	19, 780	135, 200	10, 300	18, 530	126, 700	41
42	. 8155	6. 799	11, 000	19, 810	134, 700	10, 310	18, 560	126, 200	42
43	. 8109	6. 760	11, 020	19, 830	134, 100	10, 320	18, 580	125, 600	43
44	. 8063	6. 722	11, 030	19, 860	133. 500	10, 330	18, 600	125, 000	44
45	. 8017	6. 684	11, 050	19, 890	132, 900	10, 340	18, 620	124, 400	**45**
46	. 7972	6. 646	11, 070	19, 920	132, 400	10, 360	18, 640	123, 900	46
47	. 7927	6. 609	11, 080	19, 940	131, 900	10, 370	18, 660	123, 300	47
48	. 7883	6. 572	11, 100	19, 970	131, 200	10, 380	18, 680	122, 800	48
49	7839	6. 536	11, 110	20, 000	130, 700	10, 390	18, 700	122, 200	**49**

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Table 1.

VOLATILE PETROLEUM PRODUCTS

Gravity		Density	Total heat of combustion at constant volume, Q_v			Net heat of combustion at constant pressure, Q_p			Degrees A. P. I. at 60° F.
Degrees A. P. I. at 60° F.	Specific at 60°/60° F.	Pounds per gallon	Cal./g	Btu./lb.	Btu./gal.	Cal./g	Btu./lb.	Btu./gal.	
50	0. 7796	6. 500	11, 120	20, 020	130, 100	10, 400	18, 720	121, 700	**50**
51	. 7753	6. 464	11, 140	20, 050	129, 600	10, 410	18, 740	121, 100	51
52	. 7711	6. 429	11, 150	20, 070	129, 000	10, 420	18, 760	120, 600	52
53	. 7669	6. 394	11, 160	20, 100	128, 500	10, 430	18, 780	120, 100	53
54	. 7628	6. 360	11, 180	20, 120	128, 000	10, 440	18, 800	119, 500	54
55	. 7587	6. 326	11, 190	20, 140	127, 400	10, 450	18, 810	119, 000	**55**
56	. 7547	6. 292	11, 200	20, 170	126, 900	10, 460	18, 830	118, 500	56
57	. 7507	6. 258	11, 220	20, 190	126, 400	10, 470	18, 850	118, 000	57
58	. 7467	6. 225	11, 230	20, 210	125, 800	10, 480	18, 870	117, 500	58
59	. 7428	6. 193	11, 240	20, 230	125, 300	10, 490	18, 880	116, 900	59
60	. 7389	6. 160	11, 250	20, 260	124, 800	10, 500	18, 900	116, 400	**60**
61	. 7351	6. 128	11, 270	20, 280	124, 300	10, 510	18, 920	115, 900	61
62	. 7313	6. 097	11, 280	20, 300	123, 700	10, 520	18, 930	115, 400	62
63	. 7275	6. 065	11, 290	20, 320	123, 200	10, 530	18, 950	114, 900	63
64	. 7238	6. 034	11, 300	20, 340	122, 700	10, 540	18, 960	114, 400	64
65	. 7201	6. 004	11, 310	20, 360	122, 200	10, 540	18, 980	113, 900	**65**
66	. 7165	5. 973	11, 320	20, 380	121, 700	10, 550	18, 990	113, 400	66
67	. 7128	5. 943	11, 330	20, 400	121, 200	10, 560	19, 010	112, 900	67
68	. 7093	5. 913	11, 340	20, 420	120, 700	10, 570	19, 020	112, 500	68
69	. 7057	5. 884.	11, 350	20, 440	120, 200	10, 580	19, 040	112, 000	69
70	. 7022	5. 855	11, 360	20, 460	119, 800	10, 580	19, 050	111, 500	**70**
72	. 6953	5. 797	11, 380	20, 490	118, 800	10, 600	19, 080	110, 600	72
74	. 6886	5. 741	11, 400	20, 530	117, 900	10, 610	19, 100	109, 700	74
76	. 6819	5. 685	11, 420	20, 560	116, 900	10, 630	19, 130	108, 800	76
78	. 6754	5. 631	11, 440	20, 600	116, 000	10, 640	19, 150	107, 900	78
80	. 6690	5. 578	11, 460	20, 630	115, 100	10, 650	19, 180	107, 000	**80**
82	. 6628	5. 526	11, 480	20, 660	114, 200	10, 670	19, 200	106, 100	82
84	. 6566	5. 474	11, 490	20, 690	113, 300	10, 680	19, 220	105, 200	84
86	. 6506	5. 424	11, 510	20, 720	112, 400	10, 690	19, 240	104, 400	86
88	. 6446	5. 375	11, 530	20, 750	111, 500	10, 700	19, 260	103, 500	88
90	. 6388	5. 326	11, 540	20, 780	110, 700	10, 710	19, 280	102, 700	**90**
92	. 6331	5. 278	11, 560	20, 810	109, 800	10, 720	19, 300	101, 900	92
94	. 6275	5. 232	11, 570	20, 830	109, 000	10, 740	19, 320	101, 100	94
96	. 6220	5. 186	11, 590	20, 860	108, 100	10, 750	19, 340	100, 300	96
98	. 6166	5. 140	11, 600	20, 880	107, 300	10, 760	19, 360	99, 500	98
100	. 6112	5. 096	11, 620	20, 910	106, 500	10, 770	19, 380	98, 700	**100**
105	. 5983	4. 988	11, 650	20, 970	104, 600	10, 790	19, 420	96, 800	105
110	. 5859	4. 885	11, 680	21, 020	102, 700	10, 810	19, 460	95, 100	110
115	. 5740	4. 786	11, 710	21, 070	100, 900	10, 830	19, 490	93, 300	115
120	. 5626	4. 691	11, 740	21, 120	99, 100	10, 850	19, 530	91, 600	120
125	. 5517	4. 599	11, 760	21, 170	97, 400	10, 860	19, 560	90, 000	**125**
130	. 5411	4. 511	11, 790	21, 210	95, 700	10, 880	19, 590	88, 400	130
135	. 5310	4. 427	11, 810	21, 250	94, 100	10, 900	19, 610	86, 800	135
140	. 5212	4. 345	11, 830	21, 290	92, 500	10, 910	19, 640	85, 300	140
145	. 5118	4. 267	11, 850	21, 330	91, 000	10, 920	19, 660	83, 900	145

Table 2.

HEATING VALUE OF PETROLEUM OILS

In most practical applications of the combustion of petroleum products, the process is carried out at constant pressure (atmospheric) and the water vapor formed in combustion is not condensed. For such processes, therefore, the net heat of combustion at constant pressure is the more significant quantity in making comparisons of fuels and in calculating the efficiencies of heating appliances.

Heats of Combustion of Crude Oils, Fuel Oils, and Kerosenes

The data on heats of combustion (heating values) given in Table I apply to petroleum oils free from water, ash, and sulphur with an estimated accuracy of 1 per cent. These data are based on experimental results obtained, on a total of 630 petroleum oils from 8 States and 10 foreign countries, by 5 groups of observers.

Heats of Combustion of Volatile Petroleum Products

The data on heats of combustion (heating values) given in Table II apply to volatile petroleum liquids in general with an estimated accuracy of 1 per cent. The values given are probably too high by 1 or 2 per cent for products containing unusually large amounts of aromatic hydrocarbons; for example, "vapor phase cracked" gasoline. The tabulated values should be increased by about 1 per cent to yield corresponding value for the heats of combustion of the vapor (vaporized product); that is, for those instances in which the latent heat of vaporization is supplied by the external surroundings and not by the combustion of the product.

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OIL TEMPERATURE CORRECTION FACTORS

Oil Temperature Correction Factors—to 60° F.

Observed Temperature ° F.	Degrees A. P. I. 5.0° to 9.9°	10.0° to 14.9°	15.0° to 19.9°	20.0° to 24.9°	25.0° to 29.9°	30.0° to 34.9°	35.0° to 39.9°	40.0° to 49.9°	50.0° to 59.9°
0	1.0215	1.0227	1.0235	1.0243	1.0251	1.0262	1.0276	1.0301	1.0347
2	1.0208	1.0219	1.0227	1.0235	1.0243	1.0253	1.0267	1.0291	1.0335
4	1.0201	1.0211	1.0219	1.0226	1.0234	1.0244	1.0258	1.0281	1.0324
6	1.0193	1.0203	1.0211	1.0218	1.0226	1.0236	1.0248	1.0271	1.0312
8	1.0186	1.0196	1.0203	1.0210	1.0217	1.0227	1.0239	1.0261	1.0301
10	1.0179	1.0188	1.0195	1.0202	1.0209	1.0218	1.0230	1.0251	1.0290
12	1.0171	1.0180	1.0187	1.0194	1.0201	1.0209	1.0221	1.0241	1.0278
14	1.0164	1.0173	1.0179	1.0185	1.0192	1.0200	1.0212	1.0231	1.0267
16	1.0157	1.0165	1.0171	1.0177	1.0184	1.0192	1.0203	1.0221	1.0255
18	1.0150	1.0158	1.0164	1.0169	1.0175	1.0183	1.0194	1.0211	1.0244
20	1.0144	1.0150	1.0156	1.0161	1.0167	1.0174	1.0184	1.0201	1.0232
22	1.0137	1.0142	1.0148	1.0153	1.0159	1.0165	1.0175	1.0191	1.0220
24	1.0129	1.0135	1.0140	1.0144	1.0150	1.0156	1.0166	1.0181	1.0209
26	1.0122	1.0127	1.0132	1.0136	1.0142	1.0148	1.0156	1.0171	1.0197
28	1.0115	1.0120	1.0125	1.0128	1.0133	1.0139	1.0147	1.0161	1.0186
30	1.0108	1.0112	1.0117	1.0120	1.0125	1.0130	1.0138	1.0151	1.0174
32	1.0100	1.0105	1.0109	1.0112	1.0117	1.0121	1.0129	1.0141	1.0162
34	1.0093	1.0097	1.0101	1.0104	1.0108	1.0112	1.0120	1.0131	1.0151
36	1.0085	1.0089	1.0093	1.0096	1.0100	1.0104	1.0110	1.0121	1.0139
38	1.0078	1.0082	1.0085	1.0088	1.0091	1.0095	1.0101	1.0110	1.0128
40	1.0071	1.0074	1.0077	1.0080	1.0083	1.0087	1.0092	1.0100	1.0116
42	1.0064	1.0067	1.0069	1.0072	1.0075	1.0078	1.0082	1.0090	1.0104
44	1.0057	1.0060	1.0062	1.0064	1.0066	1.0069	1.0073	1.0080	1.0093
46	1.0049	1.0052	1.0054	1.0056	1.0058	1.0061	1.0064	1.0070	1.0081
48	1.0042	1.0045	1.0046	1.0048	1.0050	1.0052	1.0055	1.0060	1.0070
50	1.0035	1.0037	1.0038	1.0040	1.0042	1.0043	1.0046	1.0050	1.0058
52	1.0028	1.0029	1.0030	1.0032	1.0034	1.0035	1.0037	1.0041	1.0046
54	1.0021	1.0022	1.0023	1.0024	1.0025	1.0026	1.0028	1.0030	1.0035
56	1.0014	1.0014	1.0015	1.0016	1.0017	1.0018	1.0018	1.0020	1.0023
58	1.0007	1.0007	1.0008	1.0008	1.0008	1.0009	1.0009	1.0010	1.0012
60	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
62	.9993	.9993	.9992	.9992	.9992	.9991	.9991	.9990	.9988
64	.9986	.9986	.9985	.9984	.9983	.9982	.9982	.9980	.9977
66	.9979	.9978	.9977	.9976	.9975	.9974	.9972	.9970	.9965
68	.9972	.9971	.9970	.9968	.9966	.9965	.9963	.9960	.9954
70	.9965	.9963	.9962	.9960	.9958	.9957	.9954	.9950	.9942
72	.9958	.9956	.9954	.9952	.9950	.9949	.9945	.9940	.9930
74	.9951	.9949	.9946	.9944	.9942	.9940	.9936	.9929	.9919
76	.9943	.9941	.9938	.9936	.9934	.9932	.9927	.9919	.9907
78	.9937	.9934	.9931	.9929	.9926	.9923	.9918	.9909	.9896
80	.9930	.9927	.9924	.9921	.9918	.9914	.9909	.9899	.9884
82	.9923	.9919	.9916	.9913	.9910	.9905	.9899	.9889	.9871
84	.9916	.9912	.9908	.9905	.9901	.9896	.9890	.9879	.9860
86	.9909	.9904	.9900	.9897	.9893	.9888	.9880	.9869	.9848
88	.9902	.9897	.9893	.9889	.9884	.9879	.9871	.9859	.9837
90	.9895	.9890	.9885	.9881	.9876	.9870	.9862	.9849	.9825
92	.9888	.9883	.9877	.9873	.9868	.9861	.9853	.9839	.9813
94	.9881	.9875	.9870	.9865	.9860	.9852	.9844	.9829	.9802
96	.9874	.9867	.9862	.9857	.9852	.9844	.9834	.9819	.9790
98	.9867	.9860	.9855	.9849	.9843	.9835	.9825	.9809	.9779
100	.9860	.9853	.9847	.9841	.9835	.9827	.9816	.9799	.9767
102	.9853	.9846	.9839	.9833	.9827	.9818	.9807	.9789	.9755
104	.9846	.9839	.9832	.9826	.9818	.9809	.9798	.9778	.9743
106	.9838	.9831	.9824	.9818	.9810	.9801	.9789	.9768	.9731
108	.9832	.9824	.9817	.9810	.9802	.9792	.9780	.9758	.9720
110	.9825	.9817	.9810	.9802	.9794	.9783	.9771	.9748	.9708
112	.9818	.9809	.9802	.9794	.9786	.9775	.9762	.9738	.9696
114	.9811	.9802	.9794	.9786	.9777	.9766	.9753	.9728	.9685
116	.9804	.9795	.9786	.9778	.9769	.9758	.9743	.9718	.9673
118	.9797	.9788	.9781	.9770	.9760	.9749	.9734	.9708	.9662
120	.9790	.9781	.9772	.9762	.9752	.9741	.9725	.9698	.9650

Compiled from Bureau of Standards Circular C410 (1936)

Multiply the volume of oil in the tank or car at the observed temperature by these factors to get the volume at 60 deg. F.

COMMERCIAL FUEL OIL STANDARDS

EFFECTIVE JANUARY 5, 1940

NATIONAL BUREAU OF STANDARDS CS12-40

TABLE 1.—*Detailed requirements for fuel oils* [a]

Grade [b]		Flash point (° F)		Pour point (° F)	Water and sediment (percent)	Carbon residue (percent)	Ash (percent)	Distillation temperatures (° F)				Viscosity seconds			
								10-percent point	90-percent point		End point	Saybolt universal (at 100° F)		Saybolt furol (at 122° F)	
Number	Description of fuel oil	Min	Max	Max	Max	Max	Max	Max	Max	Min	Max	Max	Min	Max	Min
1	Distillate oil for use in burners requiring a volatile fuel.	100 or legal	165	0	Trace	0.05 on 10% residuum [d]		410			[e] 560				
2	Distillate oil for use in burners requiring a moderately volatile fuel.	110 or legal	190	[c] 10	0.05	.25 on 10% residuum [f]		440	600						
3	Distillate oil for use in burners requiring a low-viscosity fuel.	110 or legal	230	[c] 20	.10	.15 straight			675	[g] 600		45			
5	Oil for use in burners requiring a medium viscosity fuel.	130 or legal			1.00		0.10						50	40	
6	Oil for use in burners equipped with preheaters, permitting a high viscosity fuel.	150			[h] 2.00									300	45

[a] Recognizing the necessity for low-sulfur fuel oils used in connection with heat treatment, nonferrous metal, glass and ceramic furnaces, and other special uses, a sulfur requirement may be specified in accordance with the following table:

Grade of fuel oil Number	Sulfur (maximum) Percent
1	0.5
2	.5
3	.75
5	No limit
6	No limit

Other sulfur limits may be specified only by mutual agreement between the buyer and seller.

[b] It is the intent of these classifications that failure to meet any requirement of a given grade does not automatically place an oil in the next lower grade unless in fact it meets all requirements of the lower grade.

[c] Lower or higher pour points may be specified whenever required by conditions of storage or use. However, these specifications shall not require a pour point lower than 0° F under any conditions.

[d] For use in other than sleeve-type blue-flame burners, carbon residue on 10-percent residuum may be increased to a maximum of 0.12 percent. This limit may be specified by mutual agreement between the buyer and seller.

[e] The maximum end point may be increased to 590° F when used in burners other than sleeve-type blue-flame burners.

[f] To meet certain burner requirements, the carbon-residue limit may be reduced to 0.15 percent on 10-percent residuum.

[g] The minimum distillation temperature of 600° F for 90 percent may be waived if API gravity is 26 or lower.

[h] Water by distillation, plus sediment by extraction. Sum, maximum 2.0 percent. The maximum sediment by extraction shall not exceed 0.50 percent. A deduction in quantity shall be made for all water and sediment in excess of 1.0 percent.

Commercial Standard CS12-40

COMPARISON OF DEGREES BAUME AND API WITH SPECIFIC GRAVITY

The general relationship between degrees Baumé and specific gravity is found in the following:

For liquids heavier than water—

$$\text{Sp. Gr.} = \frac{145}{145 - {}^\circ\text{ Baumé}} \text{ at } 60^\circ \text{ F.}$$

For liquids lighter than water—

$$\text{Sp. Gr.} = \frac{140}{130 + {}^\circ\text{ Baumé}} \text{ at } 60^\circ \text{ F.}$$

The corresponding relationship for degrees API is as follows.

$$\text{Sp. Gr.} = \frac{141.5}{131.5 + {}^\circ\text{ API}}$$

Deg.	Specific Gravity: Baumé: Liquids Heavier than Water	Specific Gravity: Baumé: Liquids Lighter than Water	Specific Gravity: API
0	1.000		
1.0	1.007		
2.0	1.014		
3.0	1.021		
4.0	1.028		
5.0	1.036		
6.0	1.043		
7.0	1.051		
8.0	1.058		
9.0	1.066		
10.0	1.074	1.000	1.000
11.0	1.082	.993	.993
12.0	1.090	.986	.986
13.0	1.098	.979	.979
14.0	1.107	.972	.973
15.0	1.115	.965	.966
16.0	1.124	.959	.959
17.0	1.133	.952	.953
18.0	1.142	.946	.947
19.0	1.151	.940	.940
20.0	1.160	.933	.934
21.0	1.169	.927	.928
22.0	1.179	.921	.922
23.0	1.188	.915	.916
24.0	1.198	.909	.910
25.0	1.208	.903	.904
26.0	1.218	.897	.898
27.0	1.229	.892	.893
28.0	1.239	.886	.887
29.0	1.250	.880	.882
30.0	1.261	.875	.876
31.0	1.272	.870	.871
32.0	1.283	.864	.865
33.0	1.295	.859	.860
34.0	1.306	.854	.855
35.0	1.318	.848	.850
36.0	1.330	.843	.845
37.0	1.343	.838	.840
38.0	1.355	.833	.835
39.0	1.368	.828	.830
40.0	1.381	.823	.825
41.0	1.394	.819	.820
42.0	1.408	.814	.816
43.0	1.422	.809	.811
44.0	1.436	.805	.806
45.0	1.450	.800	.802
46.0	1.465	.795	.797
47.0	1.480	.791	.793
48.0	1.495	.786	.788
49.0	1.510	.782	.784
50.0	1.526	.778	.780
51.0	1.543	.773	.775
52.0	1.559	.769	.771
53.0	1.576	.765	.767
54.0	1.593	.761	.763
55.0	1.611	.757	.759
56.0	1.629	.753	.755
57.0	1.648	.749	.751
58.0	1.667	.745	.747
59.0	1.686	.741	.743
60.0	1.706	.737	.739
61.0	1.726	.733	.735
62.0	1.747	.729	.731
63.0	1.768	.725	.728
64.0	1.790	.722	.724
65.0	1.812	.718	.720
66.0	1.835	.714	.717
67.0	1.859	.711	.713
68.0	1.883	.707	.709
69.0	1.908	.703	.706
70.0	1.933	.700	.702
71.0	1.959	.696	.699
72.0	1.986	.693	.695
73.0		.690	.692
74.0		.686	.689
75.0		.683	.685
76.0		.680	.682
77.0		.676	.679
78.0		.673	.675
79.0		.670	.672
80.0		.667	.669

VISCOSITY CONVERSION TABLE

The following table will give a comparison of various viscosity ratings so that if the viscosity is given in terms other than Saybolt Universal, it can be translated quickly by following horizontally to the Saybolt Universal column.

Kinematic Viscosity Centipoises = K	Seconds Saybolt Universal	Seconds Saybolt Furol	Seconds Redwood	Seconds Redwood Admiralty	Degrees Engler	Degrees Barbey
1.00	31	.....	29	.....	1.00	6200
2.56	35	.....	32.1	.....	1.16	2420
4.30	40	.....	36.2	5.10	1.31	1440
5.90	45	.....	40.3	5.52	1.46	1050
7.40	50	.....	44.3	5.83	1.58	838
8.83	55	.....	48.5	6.35	1.73	702
10.20	60	.....	52.3	6.77	1.88	618
11.53	65	.....	56.7	7.17	2.03	538
12.83	70	12.95	60.9	7.60	2.17	483
14.10	75	13.33	65.0	8.00	2.31	440
15.35	80	13.70	69.2	8.44	2.45	404
16.58	85	14.10	73.3	8.86	2.59	374
17.80	90	14.44	77.6	9.30	2.73	348
19.00	95	14.85	81.5	9.70	2.88	326
20.20	100	15.24	85.6	10.12	3.02	307
31.80	150	19.3	128	14.48	4.48	195
43.10	200	23.5	170	18.90	5.92	144
54.30	250	28.0	212	23.45	7.35	114
65.40	300	32.5	254	28.0	8.79	95
76.50	350	35.1	296	32.5	10.25	81
87.60	400	41.9	338	37.1	11.70	70.8
98.60	450	46.8	381	41.7	13.15	62.9
110.	500	51.6	423	46.2	14.60	56.4
121.	550	56.6	465	50.8	16.05	51.3
132.	600	61.4	508	55.4	17.50	47.0
143	650	66.2	550	60.1	19.00	43.4
154	700	71.1	592	64.6	20.45	40.3
165	750	76.0	635	69.2	21.90	37.6
176	800	81.0	677	73.8	23.35	35.2
187	850	86.0	719	78.4	24.80	33.2
198	900	91.0	762	83.0	26.30	31.3
209	950	95.8	804	87.6	27.70	29.7
220	1000	100.7	846	92.2	29.20	28.2
330	1500	150	1270	138.2	43.80	18.7
440	2000	200	1690	184.2	58.40	14.1
550	2500	250	2120	230	73.00	11.3
660	3000	300	2540	276	87.60	9.4
770	3500	350	2960	322	100.20	8.05
880	4000	400	3380	368	117.00	7.05
990	4500	450	3810	414	131.50	6.26
1100	5000	500	4230	461	146.00	5.64
1210	5500	550	4650	507	160.50	5.13
1320	6000	600	5080	553	175.00	4.70
1430	6500	650	5500	559	190.00	4.34
1540	7000	700	5920	645	204.50	4.03
1650	7500	750	6350	691	219.00	3.76
1760	8000	800	6770	737	233.50	3.52
1870	8500	850	7190	783	248.00	3.32
1980	9000	900	7620	829	263.00	3.13
2090	9500	950	8040	875	277.00	2.97
2200	10000	1000	8460	921	292.00	2.82

The viscosity is often expressed in terms of viscosimeters other than the Saybolt Universal. The formulas for the various viscosimeters are as follows:

Redwood	$K = .26\,t - \frac{188}{t}$	(British)	Saybolt Universal	$K = .22\,t - \frac{180}{t}$	American
Redwood Admiralty	$K = 2.396 - \frac{40.3}{t}$	(British)	Saybolt Furol	$K = 2.2\,t - \frac{203}{t}$	American
			Engler	$K = .147\,t - \frac{374}{t}$	German
				= Engler Degrees X 51.3	

The Barbey measures the quantity of flow per hour under constant head instead of the time for a definite quantity under varying head as do the others.

The Saybolt Furol and Redwood Admiralty are especially designed for measuring the more viscous oils and give a reading in seconds approximately one-tenth of that given for the same oil by the Saybolt Universal and Redwood respectively.

If viscosity is given at any two temperatures, the viscosity at any other temperature can be obtained by plotting the viscosity against temperature in degrees Fahrenheit on special cross section paper. The points for a given oil lie in a straight line.

Worthington Pump & Machinery Corp.

ANALYSES AND PHYSICAL PROPERTIES OF PETROLEUM OILS[1]

Source or name	Gravity, °Be	Sp gr 60°/60°F	Analysis					Btu per lb	Flash point, open cup, °F	Fire point, °F	Viscosity	
			C	H	O and N	S	H_2O				Saybolt seconds at 70°F	Engler scale at 68°F
Crude oils:												
Western	14.4	0.970	85.64	11.37	0.84	1.06	...	18,478	192	...	387	
Kern River, Calif.	15.0	0.966	.....	.....	....	0.89	0.5	18,500	102	128	...	390.0
Summerland, Calif.	15.1	0.965	.....	.....	....	0.36	1.2	18,530	100	130	...	222.1
Los Angeles City, Calif.	15.4	0.963	.....	.....	....	0.62	1.7	18,430	107	145	...	272.5
Salt Lake, Calif.	15.7	0.961	.....	.....	....	2.29	0.9	18,230	46	89	...	574.3
Western	16.4	0.957	86.58	11.61	0.74	0.82	...	18,613	172	...	380	
Western	17.4	0.950	86.37	11.30	1.14	1.60	...	18,727	230	...	250	
Sunset, Calif.	18.1	0.946	.....	.....	....	0.89	0.5	18,605	47	79	...	120.5
Coalinga, Calif.	19.4	0.938	.....	.....	....	0.48	0.4	18,550	70	93	...	80.7
Whittier, Calif.	19.4	0.938	.....	.....	....	0.61	0.0	18,810	46	84	...	34.6
Lompoc, Calif.	20.0	0.934	.....	.....	....	3.55	0.7	18,330	−1	21	...	62.5
Midcontinent	20.2	0.933	86.06	11.21	2.06	0.67	...	19,440	273	...	220	
Midway, Calif.	20.5	0.931	.....	.....	....	0.66	0.6	18,710	54	83	...	91.7
Texas	21.6	0.924	84.60	10.90	2.87	1.63	...	18,977				
Newhall, Calif.	22.1	0.921	.....	.....	....	0.35	0.2	18,890	60	83	...	118.2
Midcontinent	22.4	0.920	84.60	10.90	2.87	1.63	...	19,060	180	...	198	
Fullerton, Calif.	22.5	0.919	.....	.....	....	0.89	0.2	18,800	18	52	...	110.5
Pennsylvania	23.3	0.914	86.10	13.90	....	0.60	...	20,752				
Midcontinent	24.2	0.909	87.93	11.27	0.19	0.41	...	19,650	264	...	188	
Coyote Hills, Calif.	24.9	0.905	.....	.....	....	1.14	tr.	18,965	27	50	...	10.5
Santa Fe Springs, Calif.	34.8	0.851	.....	.....	....	0.45	...	.....	...	...	50	
	27.9	0.888	.....	.....	....	0.54	...	.....	...	...	105	
Santa Maria, Calif.	24.9	0.905	.....	.....	....	1.93	0.1	18,710	−2	20	...	19.0
Santa Paula, Calif.	25.5	0.901	.....	.....	....	0.54	0.5	18,840	6	18	...	5.8
Seepe, Calif.	26.6	0.895	.....	.....	....	0.34	0.4	18,990	18	40	...	10.6
Eastern	31.9	0.866	86.40	12.37	1.02	0.13	...	19,890	102	...	165	
Kansas	31.9	0.866	85.40	13.07	....	....	...	20,345				
West Virginia	36.8	0.841	84.30	14.10	1.60	....	...	20,818				
Pennsylvania	37.2	0.839	.....	.....	....	....	...	20,560	128	180		
Ohio	39.4	0.829	85.00	13.80	0.60	0.60	...	20,752				
Eastern	40.4	0.823	82.00	14.80	3.20	0.10	...	20,300	78	...	112	
									Closed cup		Saybolt seconds	at °F
Fuel oils:												
Mexican	10.0	1.000	88.05	7.58	1.00	3.28	...	17,500	374	...	322	250
Bakersfield, Calif.	11.1	0.992	.....	.....	....	....	1.3	18,257				
Mexican	11.9	0.987	86.90	9.36	....	3.16	...	18,050	310	...	300	250
Los Angeles City, Calif.	13.4	0.977	.....	.....	....	....	0.4	18,280				
Bakersfield, Calif.	13.6	0.975	.....	.....	....	....	...	17,600				
California	13.6	0.975	.....	.....	....	2.46	1.3	18,104				
Mexican	14.1	0.971	85.26	10.31	....	3.94	...	18,260	208	...	92	220
California	15.0	0.966	81.52	11.61	6.92	0.55	...	18,926				
Los Angeles City, Calif.	16.4	0.957	.....	.....	....	....	...	18,855	196			
Midcontinent	16.7	0.955	83.22	10.16	3.74	2.83	...	18,427	190	...	74	220
Kern River, Calif.	17.4	0.950	.....	.....	....	....	...	18,845	140			
Whittier, Calif.	17.9	0.947	.....	.....	....	....	...	17,822	148	208		
Western	18.1	0.946	86.11	11.81	1.20	0.67	...	18,790	186	...	750	100
Whittier, Calif.	18.4	0.944	.....	.....	....	1.98	1.1	18,507				
Beaumont, Texas	18.7	0.942	86.1	12.3	....	1.60	...	20,152				
Sabine, Texas	19.5	0.937	.....	.....	....	....	...	18,662	143			
Whittier, Calif.	19.7	0.936	.....	.....	....	0.72	1.1	18,240				
Saratoga, Texas	20.6	0.930	.....	.....	....	....	...	19,665	180	242		
Coalinga, Calif.	21.1	0.927	.....	.....	....	....	...	17,117	134			
Humble, Texas	21.3	0.926	.....	.....	....	....	...	19,649	166	214		
Beaumont, Texas	21.6	0.924	84.6	10.9	2.87	1.63	...	19,060	180			
Spindle Top, Texas	22.0	0.922	.....	.....	....	....	...	19,663	165	219		
Mexican	22.1	0.921	.....	.....	....	....	...	18,840	162			
Saratoga, Texas	22.4	0.920	.....	.....	....	....	...	19,263	161	226		
Humble, Texas	22.4	0.920	.....	.....	....	....	...	18,040	124	228		
Midcontinent	22.4	0.920	83.26	12.41	3.83	0.59	...	19,430	181	...	389	100
Spindle Top, Texas	22.6	0.918	.....	.....	....	....	...	19,720	163	212		
Texas	24.0	0.910	87.29	12.32	....	0.43	...	19,659	375			
Texas	24.3	0.908	87.15	12.33	....	0.32	...	19,338	370			
Midcontinent	24.5	0.907	85.40	13.07	1.12	0.15	...	19,235	179	...	350	100
Louisiana	24.7	0.906	.....	.....	....	....	...	19,908	192	219		
Louisiana	24.9	0.905	.....	.....	....	....	...	20,193	194	233		
Beaumont, Texas	25.2	0.903	.....	.....	....	....	...	19,349	222			
Kansas	25.5	0.901	.....	.....	....	....	...	18,714	157	208		
California	27.3	0.891	.....	.....	....	....	...	18,655	257			
Pennsylvania	27.8	0.888	.....	.....	....	....	...	19,700	232	280		
Pennsylvania	28.0	0.886	84.9	13.7	1.4	....	...	19,210				
Midcontinent	28.6	0.884	84.90	13.70	1.40	0.37	...	19,312	175	...	290	100
Colorado	29.1	0.881	.....	.....	....	....	...	18,103	164	205		
Kansas	30.6	0.870	.....	.....	....	....	...	19,210	130	181		
Indiana	32.1	0.865	.....	.....	....	....	...	19,400	212	318		
Midcontinent	32.3	0.864	84.82	13.09	2.05	0.36	...	19,511	160	...	76	100
Midcontinent	35.9	0.845	84.36	13.21	1.09	0.32	...	19,627	154	...	42	100
West Virginia	36.8	0.841	84.3	14.1	1.6	....	...	21,240				
Pennsylvania	37.6	0.837	.....	.....	....	....	...	19,700	232	280		
Asphalt oil	13.4	0.977	.....	.....	....	....	...	20,442	...	376		
Gas oil	16.2	0.958	86.16	9.05	3.06	0.30	...	16,960	195	...	98	220
Steamer oil	21.1	0.927	.....	.....	....	....	...	19,291	268	322		
Kerosene, 150°	47.4	0.791	85.16	14.33	0.51	....	...	19,922	110			
Oil tar	....	1.150	92.00	6.13	0.22	0.33	...	17,300	485	...	418	220
Coal tar	....	1.250	89.20	4.95	5.27	0.58	...	15,800	530	...	490	220

[1] Compiled from Gebhardt, "Steam Power Plant Engineering"; Babcock & Wilcox Company, "Steam"; Heine Safety Boiler Company, "Steam Boiler Engineering"; Report of Committee on Petroleum, 1917; Rufus T. Strohm, "Oil Fuel for Steam Boilers."

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CHARACTERISTICS OF CARBURETING OILS[1]

Sample designation	Gas oil (A)	Gas oil (B)	Gas oil (C)	Heavy oil (1)	Heavy oil (2)	Heavy oil (3)	Heavy oil with some cracker tar (4)	Heavy oil containing cracker tar (5)
A.P.I. gravity at 77°F	35.1	32.5	30.3	21.1	17.2	15.4	17.3	13.9
Coke, per cent	0.22	0.62	0.02	3.98	9.05	7.10	4.62	4.11
Sulphur, per cent				1.18	2.77	0.60	0.98	0.58
Distillation test:								
Per cent by volume								
Below 400°F	1.3	1.4	0.9					
400 to 450	15.8	7.0	10.0					
450 to 500	26.0	15.3	26.0		0.6		4.5	3.9
500 to 550	20.9	18.9	31.9	1.6	2.9	2.0	11.0	12.4
550 to 600	14.8	17.4	16.7	5.2	5.6	4.3	12.4	16.0
600 to 650	8.6	13.3	8.3	9.1	22.2	12.1	16.1	15.4
650 to 700	6.7	9.5	2.5	26.8	24.2	31.9	14.4	16.0
700 to 750	5.6	8.2	3.5	14.0		32.1	30.0	20.2
Residue and loss	0.3	2.0	0.2	43.3*	44.5†	17.6	11.6	16.1
Below 600°F	78.8	60.0	85.5	6.8	9.1	6.3	27.9	32.3
Above 600°F	20.9	38.0‡	14.3	49.9	46.4	66.1	60.5	51.6
Hydrocarbon test:								
Per cent by volume								
Paraffins	73.0	45.0	44.6	49.0	32.0	34.9	48.3	35.7
Naphthenes	9.0	19.0	43.0	23.0	48.0	36.3	21.7	27.9
Aromatics	4.0	10.0	8.0	8.4	0.8	12.0	12.0	14.4
Olefins	14.0	26.0	4.4	19.6	19.2	16.8	18.0	22.0
Saturated compounds	82.0	64.0	87.6	72.0	80.0	71.2	70.0	63.6
Aromatics and unsaturates	18.0	36.0	12.4	28.0	20.0	28.8	30.0	36.4
Cracking test:								
Optimum temperature, °F	1330–1390	1380–1425	1380–1410	1350–1500	1350–1450	1300–1450	1350–1450	1300–1425
Btu in gas per gal	104,000	101,500	96,500	108,100	96,900	96,000	84,000	74,500
Btu of oil per cu ft	1,750	1,750	1,595	1,775	1,870	1,741	1,705	1,770
Cu ft of oil gas per gal	59.5	58.0	60.5	60.8	51.8	55.1	49.3	42.0

[1] Jerome J. Morgan, "American Gas Practice."
* Begins to crack at 705° F.
† Decomposes at 672° F.
‡ Includes 7.0 per cent distilling between 750° and 817° F.

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GAS OIL EFFICIENCY

Where gas oil is used for enriching carburetted water gas and no blow-run is made the following formula is generally employed to show the enriching value of the oil in B.t.u. per gallon.

$$\text{B.t.u. per Gal.} = \frac{1000\ (F - B)}{G} + OB$$

where F = B.t.u. per cu. ft. of the finished carburetted water gas.
B = B.t.u. per cu. ft. of the blue gas. (In lack of definite information frequently assumed to be 300.)
G = Gallons of oil per thousand cubic feet.
O = Cubic feet of oil gas produced per gallon of oil. (This is generally from 65 to 70 cu. ft.)

CALCULATION OF TERZIAN FACTORS FOR CARBURETTED WATER GAS MADE WITH HEAVY OIL

The development of the heavy oil process for making carburetted water gas has necessitated the conducting of plant scale tests under varied operating conditions. From the study of the operating results of these tests, a formula called the "Terzian Factor" was developed for comparing operating results, and has been successfully used. The formula for the "Terzian Factor" is:

$$\text{Terzian Factor} = \frac{K}{A} = \frac{10\,F + 100\,C}{A}$$

Where $K = 10\,F + 100\,C$
F = Gen. Fuel used, Lb./Mcf.
C = Oil used, Gal./Mcf.
A = Btu per cu. ft. Make Gas

When operating with a fairly uniform fuel and oil, operating results obtained under extremely varying conditions of operations can be successfully compared by the use of this formula; the smaller the numerical value of the Terzian Factor, the better gasification efficiencies.

It has been found in practice that the Terzian Factor, or the relation of K to the make gas Btu is practically constant under varying operating conditions, and varying amounts of generator fuel per Mcf, when producing a carburetted water gas of 400 to 700 Btu per cu. ft. calorific value, and operating with heavy oil of a fairly uniform quality.

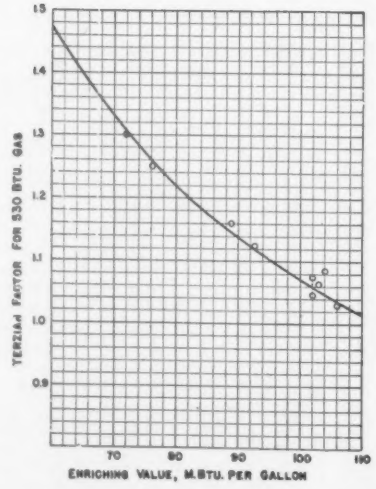
A study of heavy oil operating results of various plants for the last six years indicates that we can use the "Terzian Plant Constant" as a means of checking the plant operating results including the tar production. The formula for the "Plant Constant" is:

$$\text{Terzian Plant Constant} = \frac{K_1}{A} = \frac{10F + 100(C\text{-}T)}{A}$$

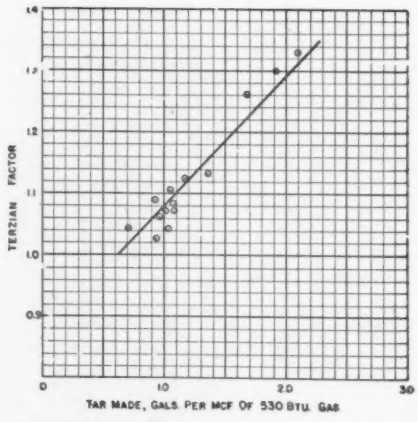
Where K_1 = Plant Constant
T = Tar Made gals./Mcf
F. C. & A. are as shown above

The "Plant Constant" varies between .88 and .92, primarily due to the quality of the heavy oil used. Oils of high enrichment value give a low "Plant Constant," and oils of low enriching value give the higher figure. There is also a slight variation between different plants, even though the quality of the oil might be practically the same. This variation is due to certain plant characteristics such as the quality of fuel used, technique of operation, miscellaneous plant equipment, etc.

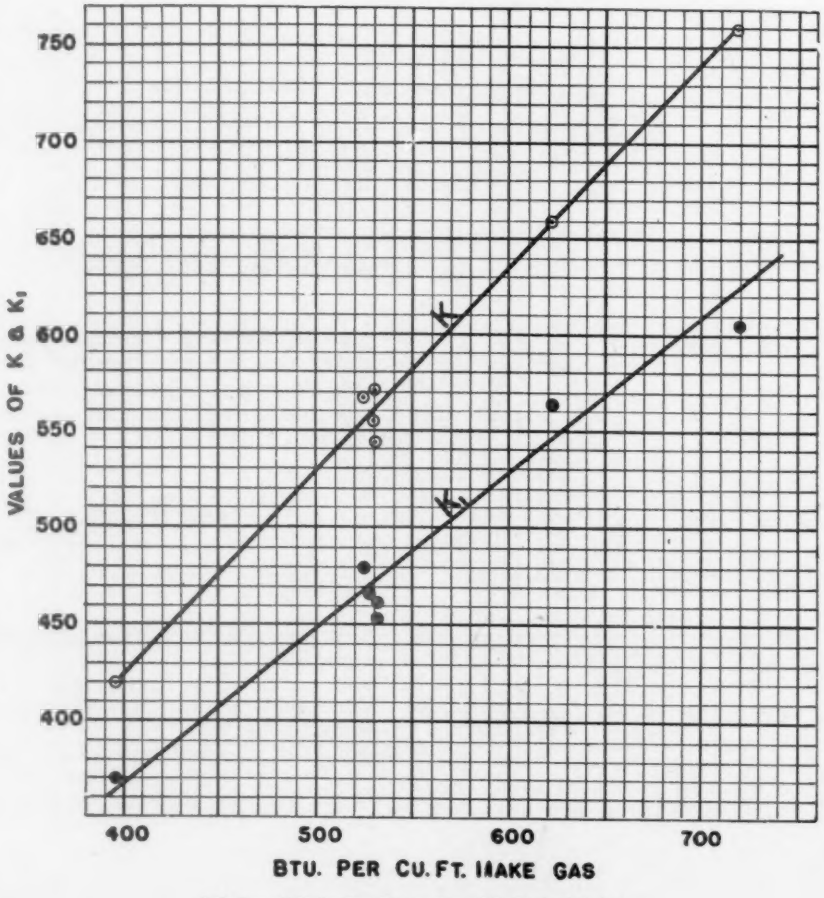
H. G. Terzian, 1936 AGA Production Conference.



Typical Relation of Terzian Factor to Enriching Value of Heavy Oil when Making 530 Btu gas.



Typical Relation of Terzian Factor to Gals. Tar Made per Mcf of 530 Btu Gas When Using Heavy Oils of Varying Enriching Qualities.



Relation of Make Gas Btu to K and K_1 Typical Values.

TANK FORMULAS

The following formulas have been selected to facilitate the rapid calculation of capacities of various types of storage tanks in gallons and barrels.

Uniform Notations:

B = Capacity of each dished head in United States gallons.
B_2 = Total capacity of both dished heads in United States gallons.
C_B = Total capacity of tank in barrels (of 42 United States gallons).
C_G = Total capacity of tank in United States gallons.
C_{GF} = Capacity of cylindrical portion of tank in United States gallons per foot length. (Flat heads.)
D = Inside diameter of tank in feet.
G = Liquid contents of partially filled tank in United States gallons.
L = Length of cylindrical portion of tank in feet.
b = Dish of head, bead line to inside of plate (height of arc) in inches.
d = Inside diameter of tank in inches.
h = Depth or height of liquid in tank in inches.
l = Length of cylindrical portion of tank in inches.
r = Radius of dished head (where different from tank diameter) in inches.
k = Per cent of total capacity of horizontal tanks.

Capacity of Vertical Cylindrical Tanks with Flat Heads

R = Inside radius of tank in feet.
H = Height of liquid in feet.
$C_{GF} = 23.501\ R^2$ = Capacity in United States gallons, per foot depth.
$C_G = 23.501 R^2H$ = Total capacity in United States gallons.
$C_B = 0.56\ R^2H$ = Total capacity in barrels (of 42 United States gallons).

Capacity of Horizontal Cylindrical Tanks with Flat Heads

$C_{GF} = 0.0408d^2$ = Capacity in United States gallons per foot length.
$C_G = 0.0034d^2l$ = Total capacity in United States gallons.
$C_G = 5.875D^2L$ = Total capacity in United States gallons.
$C_B = 0.14\ D^2L$ = Total capacity in barrels (of 42 United States gallons).

Capacity of Horizontal Cylindrical Tanks with Dished Heads

(where radius of dished head equals diameter of tank)

$C_G = 0.0034d^2l + 0.0004664d^3$ = Total capacity in United States gallons.
$C_G = 5.875D^2L + 0.806D^3$ = Total capacity in United States gallons.
$C_B = 0.14D^2L + 0.019D^3$ = Total capacity in barrels (of 42 United States gallons).

Capacity of Dished Head of any Radius

$B = 0.0045333b^2\ (3r - b)$ = Capacity of each dished head in United States gallons.

Capacity of Spherical Tanks

$C_G = 0.0022666d^3$ = Total capacity in United States gallons.
$C_G = 3.9168D^3$ = Total capacity in United States gallons.
$C_B = 0.093257D^3$ = Total capacity in barrels (of 42 United States gallons).

Liquid Contents of partially filled Tanks

Horizontal Cylindrical Tanks with Flat Heads:

G = Liquid contents in United States gallons

$$= \frac{1}{231}\left[0.004363\ d^2\ \mathrm{Cos}^{-1}\ \frac{d-2h}{d} - \frac{d-2h}{2}\sqrt{h(d-h)}\right].$$

The notation $\mathrm{Cos}^{-1}\ \frac{d-2h}{d}$ (read inverse cosine of $\frac{d-2h}{d}$, or arc cosine $\frac{d-2h}{d}$) means the angle (in degrees) whose cosine is equal to $\frac{d-2h}{d}$.

The use of this inverse function can best be illustrated by an example:

Find the number of gallons contained in a horizontal cylindrical tank with flat heads, if the tank inside diameter is 100 inches, the length 50 inches, and the tank is filled with liquid to a depth of 10 inches. Substituting in the above formula,

$$G = \frac{50}{231}\left[0.004363(100)^2\mathrm{Cos}^{-1}\ \frac{100-20}{100} - \frac{100-20}{2}\sqrt{10(100-10)}\right],$$

$$G = 0.21645\left[43.63\ \mathrm{Cos}^{-1}\ 0.80 - 40\sqrt{900}\right].$$

But, as stated above, $\mathrm{Cos}^{-1}\ 0.80$ means "the angle of

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CAPACITIES OF DISHED HEADS

The type of dished heads and the total capacity of two such heads for tanks of various diameters may be obtained from the following:

	Standard Dish Type			Shallow Dish Type		
Diameter of Tank	Dish Radius	Height of Bulge*	Capacity 2 Heads-Gallons	Dish Radius	Height of Bulge*	Capacity 2 Heads-Gallons
5'-6"	5'-6"	9¼"	140	10'-0"	5¼"	80
6'-0"	6'-0"	10¼"	180	10'-0"	6¼"	110
6'-6"	6'-6"	11 "	230	10'-0"	7¼"	150
7'-0"	7'-0"	11¾"	285	10'-0"	8¼"	200
7'-6"	7'-6"	12½"	350	16'-5"	6 "	165
8'-0"	8'-0"	13¼"	425	16'-5"	6¾"	210
8'-6"	8'-6"	14¼"	510	16'-5"	7½"	265
9'-0"	9'-0"	15 "	605	16'-5"	8¼"	330
9'-6"	9'-6"	15¾"	710	16'-5"	9 "	405
10'-0"	10'-0"	16½"	825	25'-0"	6¾"	340
10'-6"	10'-6"	17½"	955	25'-0"	7½"	420
11'-0"	11'-0"	18¼"	1100	25'-0"	8¼"	500
12'-0"	12'-0"	20 "	1435	25'-0"	9½"	690

* The "Height of Bulge" is measured from a plane perpendicular to the axis of the tank and passing through the end of the cylindrical section of the head flange to the center point on the outside of the head. The length of the cylindrical part of the tank plus twice the height of the bulge will equal the total length of the tank measured along its axis.

The material for this table was obtained from "Steel Plates," a handbook compiled by Bethlehem Steel Co.

which the cosine is 0.80." From a table of natural cosines the angle is found to be 36° 52′ or 36.87°. Substituting this value for Cos^{-1} 0.80 we have,

$G = 0.21645\ (43.63 \times 36.87 - 1200)$,
$G = 0.21645 \times 408.6$,
$G = 88.45$ gallons.

Note: In calculating liquid contents of partially filled tanks, use formula for tanks up to half full. For tanks over half full, calculate capacity of unfilled portion and subtract from capacity of full tank.

Spherical Tanks:

G = Liquid contents in United States gallons
$= 0.0022666h^2(3d - 2h)$.

Liquid Contents of partially filled Horizontal Cylindrical Tanks—with Flat Heads (by use of Tables 2 and 3).

(1) Tank less than half full:

In order to find the gallons of liquid in a horizontal cylindrical tank with flat heads when tank is less than half full:

Find the total capacity of the tank, C_G, either by calculating from the formulas or by finding the capacity per foot length, C_{GF}, from Table 2 and multiplying by the length of the tank in feet.

Divide the depth of liquid, h, by the inside diameter of the tank, d, and by referring to Table 3 find the k corresponding to the h/d just found.

The United States gallons of liquid in the tank are then,

$$\text{United States gallons} = \frac{C_G \times k}{100}.$$

Example:

$d = 96$ inches;
$L = 30.5$ feet;
$h = 32$ inches.

From Table 2, $C_{GF} = 376.01$;
then $C_G = C_{GF}L = 376.01 \times 30.5 = 11{,}468$ gallons;

$$\frac{h}{d} = \frac{32}{96} = 0.333.$$

From Table 3, $k = 29.1391$;
therefore, United States gallons in tank =

$$\frac{11{,}468 \times 29.1391}{100} = 3341.7.$$

(2) Tank over half full:

To find the liquid contents of a tank over half full, let h′ = depth of *unfilled portion*. The calculation should then proceed as for a tank less than half full using h′ instead of h. The result obtained will then be the capacity of the *unfilled portion* of the tank and must be subtracted from the total capacity of the tank, C_G, to find the quantity of liquid in the tank.

Table 2

CAPACITIES OF HORIZONTAL CYLINDRICAL TANKS IN UNITED STATES GALLONS PER FOOT LENGTH FLAT AND OF DISHED HEADS (WHERE r=d)

1 gallon = 231 cubic inches = 0.13368 cubic foot
1 cubic foot = 7.4805 gallons

Inside diameter of tank in inches	Capacity of cylindrical portion of tank per foot length	Total capacity of both dished heads	Inside diameter of tank in inches	Capacity of cylindrical portion of tank per foot length	Total capacity of both dished heads	Inside diameter of tank in inches	Capacity of cylindrical portion of tank per foot length	Total capacity of both dished heads
d	C_{GF}	B_1	d	C_{GF}	B_1	d	C_{GF}	B_1
12	5.88	0.81	48	94.00	51.58	84	287.88	276.45
13	6.90	1.02	49	97.96	54.87	85	294.78	286.44
14	8.00	1.28	50	102.00	58.30	86	301.76	296.67
15	9.18	1.57	51	106.12	61.87	87	308.82	307.14
16	10.44	1.91	52	110.32	65.58	88	315.96	317.85
17	11.79	2.29	53	114.61	69.44	89	323.18	328.81
18	13.22	2.72	54	118.97	73.44	90	330.48	340.02
19	14.73	3.20	55	123.42	77.60	91	337.86	351.48
20	16.32	3.73	56	127.95	81.91	92	345.33	363.19
21	17.99	4.32	57	132.56	86.38	93	352.88	375.16
22	19.75	4.97	58	137.25	91.00	94	360.51	387.40
23	21.58	5.67	59	142.02	95.79	95	368.22	399.89
24	23.50	6.45	60	146.88	100.75	96	376.01	412.65
25	25.50	7.29	61	151.82	105.87	97	383.89	425.68
26	27.58	8.20	62	156.84	111.16	98	391.84	438.99
27	29.74	9.18	63	161.94	116.63	99	399.88	452.56
28	31.99	10.24	64	167.12	122.27	100	408.00	466.41
29	34.31	11.38	65	172.38	128.09	101	416.20	480.55
30	36.72	12.59	66	177.72	134.09	102	424.48	494.96
31	39.21	13.89	67	183.15	140.28	103	432.85	509.66
32	41.78	15.28	68	188.66	146.66	104	441.29	524.65
33	44.43	16.76	69	194.25	153.22	105	449.82	539.93
34	47.16	18.33	70	199.92	159.98	106	458.43	555.51
35	49.98	20.00	71	205.67	166.93	107	467.12	571.38
36	52.88	21.76	72	211.51	174.09	108	475.89	587.55
37	55.86	23.63	73	217.42	181.44	109	484.74	604.02
38	58.92	25.59	74	223.42	189.00	110	493.68	620.80
39	62.06	27.67	75	229.50	196.77	111	502.70	637.88
40	65.28	29.85	76	235.66	204.74	112	511.80	655.28
41	68.58	32.15	77	241.90	212.93	113	520.98	672.99
42	71.97	34.56	78	248.23	221.34	114	530.24	691.01
43	75.44	37.08	79	254.63	229.96	115	539.58	709.36
44	78.99	39.73	80	261.12	238.80	116	549.00	728.02
45	82.62	42.50	81	267.69	247.87	117	558.51	747.01
46	86.33	45.40	82	274.34	257.17	118	568.10	766.33
47	90.13	48.42	83	281.07	266.69	119	577.77	785.98
						120	587.52	805.96

Capacity for Flat Heads = $C_{GF}L$ Capacity for Dished Heads = $C_{GF}L + B_1$

Table 3

TABLE FOR GAGING HORIZONTAL CYLINDRICAL TANKS WITH FLAT HEADS—PER CENT OF TOTAL CAPACITY—k

$\frac{h}{d}$	k	$\frac{h}{d}$	k	$\frac{h}{d}$	k	$\frac{h}{d}$	k
.001	.0053	.043	1.4940	.085	4.0980	.127	7.3836
.002	.0152	.044	1.5460	.086	4.1694	.128	7.4686
.003	.0279	.045	1.5986	.087	4.2409	.129	7.5539
.004	.0429	.046	1.6515	.088	4.3128	.130	7.6393
.005	.0600	.047	1.7052	.089	4.3852	.131	7.7251
.006	.0788	.048	1.7594	.090	4.4579	.132	7.8112
.007	.0992	.049	1.8141	.091	4.5310	.133	7.8975
.008	.1212	.050	1.8692	.092	4.6043	.134	7.9841
.009	.1445	.051	1.9250	.093	4.6781	.135	8.0709
.010	.1692	.052	1.9813	.094	4.7522	.136	8.1582
.011	.1952	.053	2.0382	.095	4.8267	.137	8.2456
.012	.2223	.054	2.0955	.096	4.9016	.138	8.3332
.013	.2507	.055	2.1533	.097	4.9767	.139	8.4212
.014	.2800	.056	2.2115	.098	5.0523	.140	8.5094
.015	.3104	.057	2.2703	.099	5.1282	.141	8.5979
.016	.3419	.058	2.3296	.100	5.2044	.142	8.6867
.017	.3743	.059	2.3894	.101	5.2810	.143	8.7757
.018	.4077	.060	2.4496	.102	5.3579	.144	8.8651
.019	.4421	.061	2.5103	.103	5.4351	.145	8.9546
.020	.4773	.062	2.5716	.104	5.5126	.146	9.0443
.021	.5134	.063	2.6332	.105	5.5905	.147	9.1343
.022	.5503	.064	2.6952	.106	5.6688	.148	9.2246
.023	.5881	.065	2.7578	.107	5.7474	.149	9.3153
.024	.6267	.066	2.8209	.108	5.8262	.150	9.4061
.025	.6660	.067	2.8843	.109	5.9054	.151	9.4971
.026	.7061	.068	2.9482	.110	5.9850	.152	9.5884
.027	.7470	.069	3.0125	.111	6.0648	.153	9.6799
.028	.7886	.070	3.0772	.112	6.1449	.154	9.7717
.029	.8310	.071	3.1424	.113	6.2254	.155	9.8638
.030	.8742	.072	3.2081	.114	6.3062	.156	9.9560
.031	.9179	.073	3.2740	.115	6.3872	.157	10.0485
.032	.9624	.074	3.3405	.116	6.4687	.158	10.1414
.033	1.0075	.075	3.4073	.117	6.5503	.159	10.2343
.034	1.0534	.076	3.4747	.118	6.6323	.160	10.3275
.035	1.0998	.077	3.5423	.119	6.7147	.161	10.4211
.036	1.1469	.078	3.6104	.120	6.7972	.162	10.5147
.037	1.1947	.079	3.6789	.121	6.8802	.163	10.6086
.038	1.2431	.080	3.7478	.122	6.9633	.164	10.7029
.039	1.2921	.081	3.8170	.123	7.0469	.165	10.7972
.040	1.3417	.082	3.8867	.124	7.1307	.166	10.8919
.041	1.3919	.083	3.9568	.125	7.2147	.167	10.9868
.042	1.4427	.084	4.0273	.126	7.2991	.168	11.0819

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Table 3—Continued

$\frac{h}{d}$	k	$\frac{h}{d}$	k	$\frac{h}{d}$	k	$\frac{h}{d}$	k
.169	11.1771	.211	15.3697	.253	19.8815	.295	24.6495
.170	11.2728	.212	15.4737	.254	19.9923	.296	24.7657
.171	11.3685	.213	15.5778	.255	20.1033	.297	24.8820
.172	11.4645	.214	15.6821	.256	20.2143	.298	24.9984
.173	11.5606	.215	15.7866	.257	20.3255	.299	25.1149
.174	11.6571	.216	15.8914	.258	20.4369	.300	25.2315
.175	11.7538	.217	15.9962	.259	20.5483	.301	25.3483
.176	11.8505	.218	16.1013	.260	20.6600	.302	25.4652
.177	11.9477	.219	16.2066	.261	20.7718	.303	25.5822
.178	12.0450	.220	16.3120	.262	20.8837	.304	25.6992
.179	12.1425	.221	16.4175	.263	20.9957	.305	25.8165
.180	12.2403	.222	16.5232	.264	21.1079	.306	25.9337
.181	12.3382	.223	16.6291	.265	21.2202	.307	26.0511
.182	12.4364	.224	16.7352	.266	21.3326	.308	26.1686
.183	12.5347	.225	16.8415	.267	21.4453	.309	26.2863
.184	12.6332	.226	16.9480	.268	21.5580	.310	26.4039
.185	12.7320	.227	17.0545	.269	21.6708	.311	26.5218
.186	12.8309	.228	17.1612	.270	21.7839	.312	26.6397
.187	12.9301	.229	17.2682	.271	21.8969	.313	26.7578
.188	13.0296	.230	17.3753	.272	22.0102	.314	26.8759
.189	13.1291	.231	17.4825	.273	22.1236	.315	26.9941
.190	13.2290	.232	17.5899	.274	22.2371	.316	27.1125
.191	13.3290	.233	17.6975	.275	22.3507	.317	27.2309
.192	13.4291	.234	17.8052	.276	22.4645	.318	27.3494
.193	13.5296	.235	17.9131	.277	22.5784	.319	27.4681
.194	13.6302	.236	18.0212	.278	22.6924	.320	27.5868
.195	13.7310	.237	18.1294	.279	22.8065	.321	27.7057
.196	13.8320	.238	18.2378	.280	22.9209	.322	27.8246
.197	13.9332	.239	18.3462	.281	23.0352	.323	27.9437
.198	14.0345	.240	18.4550	.282	23.1498	.324	28.0627
.199	14.1361	.241	18.5638	.283	23.2644	.325	28.1820
.200	14.2379	.242	18.6727	.284	23.3791	.326	28.3013
.201	14.3399	.243	18.7819	.285	23.4941	.327	28.4207
.202	14.4420	.244	18.8912	.286	23.6090	.328	28.5402
.203	14.5443	.245	19.0007	.287	23.7241	.329	28.6599
.204	14.6468	.246	19.1102	.288	23.8395	.330	28.7795
.205	14.7495	.247	19.2199	.289	23.9549	.331	28.8992
.206	14.8525	.248	19.3298	.290	24.0703	.332	29.0192
.207	14.9555	.249	19.4399	.291	24.1859	.333	29.1391
.208	15.0587	.250	19.5501	.292	24.3017	.334	29.2592
.209	15.1621	.251	19.6605	.293	24.4174	.335	29.3794
.210	15.2659	.252	19.7710	.294	24.5334	.336	29.4996

Table 3—Concluded

$\frac{h}{d}$	k	$\frac{h}{d}$	k	$\frac{h}{d}$	k	$\frac{h}{d}$	k
.337	29.6199	.378	34.6221	.419	39.7321	.460	44.9125
.338	29.7403	.379	34.7456	.420	39.8577	.461	45.0394
.339	29.8608	.380	34.8691	.421	39.9834	.462	45.1664
.340	29.9814	.381	34.9927	.422	40.1092	.463	45.2933
.341	30.1021	.382	35.1165	.423	40.2350	.464	45.4203
.342	30.2228	.383	35.2402	.424	40.3608	.465	45.5473
.343	30.3437	.384	35.3640	.425	40.4866	.466	45.6743
.344	30.4645	.385	35.4879	.426	40.6125	.467	45.8014
.345	30.5856	.386	35.6119	.427	40.7384	.468	45.9284
.346	30.7067	.387	35.7359	.428	40.8645	.469	46.0555
.347	30.8279	.388	35.8599	.429	40.9904	.470	46.1826
.348	30.9491	.389	35.9840	.430	41.1165	.471	46.3096
.349	31.0705	.390	36.1082	.431	41.2426	.472	46.4368
.350	31.1918	.391	36.2324	.432	41.3687	.473	46.5639
.351	31.3134	.392	36.3567	.433	41.4949	.474	46.6911
.352	31.4350	.393	36.4810	.434	41.6211	.475	46.8183
.353	31.5566	.394	36.6055	.435	41.7474	.476	46.9454
.354	31.6783	.395	36.7299	.436	41.8735	.477	47.0726
.355	31.8002	.396	36.8544	.437	41.9998	.478	47.1998
.356	31.9220	.397	36.9789	.438	42.1261	.479	47.3269
.357	32.0440	.398	37.1036	.439	42.2526	.480	47.4541
.358	32.1661	.399	37.2282	.440	42.3789	.481	47.5815
.359	32.2882	.400	37.3530	.441	42.5053	.482	47.7087
.360	32.4104	.401	37.4778	.442	42.6318	.483	47.8359
.361	32.5327	.402	37.6026	.443	42.7583	.484	47.9632
.362	32.6550	.403	37.7275	.444	42.8847	.485	48.0904
.363	32.7774	.404	37.8524	.445	43.0113	.486	48.2177
.364	32.8999	.405	37.9774	.446	43.1379	.487	48.3450
.365	33.0225	.406	38.1025	.447	43.2646	.488	48.4722
.366	33.1451	.407	38.2275	.448	43.3911	.489	48.5996
.367	33.2678	.408	38.3526	.449	43.5178	.490	48.7269
.368	33.3906	.409	38.4778	.450	43.6445	.491	48.8542
.369	33.5134	.410	38.6030	.451	43.7712	.492	48.9814
.370	33.6363	.411	38.7283	.452	43.8979	.493	49.1087
.371	33.7593	.412	38.8537	.453	44.0245	.494	49.2360
.372	33.8823	.413	38.9790	.454	44.1514	.495	49.3634
.373	34.0054	.414	39.1044	.455	44.2782	.496	49.4907
.374	34.1287	.415	39.2298	.456	44.4050	.497	49.6180
.375	34.2519	.416	39.3553	.457	44.5318	.498	49.7453
.376	34.3752	.417	39.4809	.458	44.6587	.499	49.8727
.377	34.4986	.418	39.6064	.459	44.7856	.500	50.0000

CONSUMERS' METERS

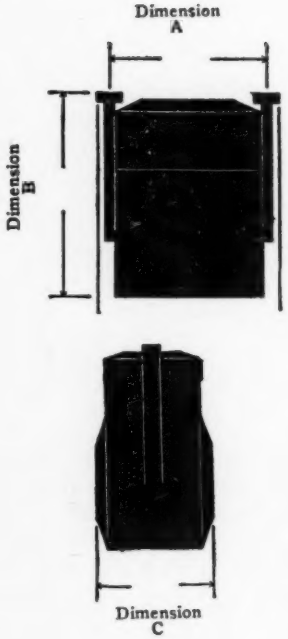
CAPACITIES, WEIGHTS, ETC., OF AMERICAN TINNED STEELCASE METERS

(Now regularly manufactured)

The dimensions are expressed in inches.

The rated gas capacity is given in cubic feet an hour at ½-inch differential

Size and type	Rated capacity	Connections threaded for iron pipe	Dimensions A	Dimensions B	Dimensions C	Proving circle cu. ft.	Cu. ft. per rev. of tang.	Approx. shipping weight pounds
2B	65	⅜" or ½"	9"	11⅝"	6 1/16"	1	1/20	9
5B	150	½"	11¼"	16¼"	9 9/16"	2	1/6	17
10B	300	¾"	13⅜"	18½"	11¼"	5	5/17	25
20B	450	1"	16 1/16"	22"	12⅞"	5	5/11	36
30B	600	1¼"	18¼"	26⅛"	15"	5	5/7	52
60B	1300	1½"	24"	31⅜"	21"	10	1 3/7	125
100B	1800	2"	27"	36¼"	23¾"	20	2½	200
200B	3200	2½"	33¾"	43¼"	30¾"	50	5	340
5M	210	½"	11¼"	16 7/16"	9⅞"	2	1/6	18
5MS	300	¾"	11⅜"	16½"	9½"	2	1/6	19
10M	425	¾"	12 15/16"	17 15/16"	10 15/16"	5	5/18	24
20A	600	1"	16⅛"	22⅛"	14½"	5	½	42
30M	900	1¼"	18½"	24⅞"	15¾"	5	⅝	57
60M	1600	1½"	25⅜"	33⅛"	20⅝"	20	2	142
150A	3400	2½"	31 3/16"	43¾"	27⅛"	50	5	355
6C	600	1¼"	14⅜"	19¾"	13¼"	10	½	38
11C	1100	2"	19 13/16"	27¾"	16⅞"	10	1 1/9	90
25C	2500	2½"	25⅜"	34"	24½"	20	2½	185
40C	4000	3"	29⅛"	38½"	29½"	50	4 1/6	295
60C	6000	4"	36¾"	45"	35⅜"	100	10	480



All "C" type meters are equipped with galvanized straight threaded nipples of standard pipe thread and will connect direct to standard iron pipe service fittings, requiring no meter connections or special threads.

SPECIFICATIONS OF AMERICAN IRONCASE METERS

Type	Maximum working pressure, pounds	Type and size of connections	Low-pressure capacities, cubic feet an hour: ½" water differential	Low-pressure capacities, cubic feet an hour: 2" water differential	Shipping weight pounds each
2B*	5	⅜" or ½"	100	210	15
3B	5	⅜" or ½"	145	300	35
5B	5	¾", 1" or 1¼" M.C.	175	370	40
5B*	5	¾", 1" or 1¼" M.C.	175	370	19½
5B	25	1" M.P.T.	175	370	45
10B	5	1" or 1¼" M.C.	250	570	50
10B	100	1" F.P.T.	250	570	90
20B	10	1¼" or 1½" M.C.	350	700	90
25B	10	1¼" M.C.	400	900	110
25B	100	1¼" F.P.T.	400	900	120
25B	250	1¼" F.P.T.	400	900	180
30B	15	1½" M.C.	550	1100	160
35B	15	1½" M.C.	650	1500	170
35B	100	1½" F.P.T.	650	1500	180
60B	20	2" M.C.	950	2000	290
60B	100	2" F.P.T.	950	2000	300
80B	20	2" F.P.T.	1200	2500	320
80B	100	2" F.P.T.	1200	2500	330
80B*	100	2" Ser. 15 Flange	1200	2500	160
80B	250	2" F.P.T.	1200	2500	430
250B	75	4" F.P.T.	3000	6000	530
250B	100	4" F.P.T.	3000	6000	540
250B*	100	4" Ser. 15 Flange	3000	6000	325
250B	250	4" F.P.T.	3000	6000	730
500B	75	4" F.P.T.	4800	10000	960
500B	100	4" F.P.T.	4800	10000	970
500B	250	4" F.P.T.	4800	10000	1340

M.C.—Malleable iron standard meter connections are required.
F.P.T.—Female pipe thread.
M.P.T.—Male pipe thread.
* Aluminumcase Meters.

American Meter Company, Inc.

CAPACITIES OF AMERICAN IRONCASE METERS AT HIGH PRESSURE

These values are the recommended maximum hourly rates expressed in cubic feet at four-ounce base pressure when measuring gas at high pressure.
Specific gravity of gas, 0.60

Gage pressure	Type of Meter 20B	25B	30B	35B	60B	80B	250B	500B
4 oz.	700	900	1100	1500	2000	2500	6000	10000
5 lb.	900	1100	1400	1900	2500	3100	7500	12500
10 lb.	1000	1300	1600	2200	3000	3700	8900	15000
15 lb.	....	1500	1900	2600	3400	4300	10000	17000
20 lb.	....	1700	....	2900	3800	4800	12000	19000
30 lb.	....	2100	....	3500	4700	5800	14000	23000
50 lb.	....	2800	....	4600	6100	7700	18000	31000
75 lb.	....	3500	....	5900	7900	9900	24000	39000
100 lb.	....	4300	....	7100	9500	12000	28000	47000
150 lb.	....	5600	....	....	....	15000	37000	62000
200 lb.	....	6800	....	....	....	19000	46000	76000
250 lb.	....	7900	....	....	....	22000	53000	88000

Specific gravity	Multiply by
0.45	1.15
0.60	1.00
1.00	0.78
1.20	0.71
1.50	0.63

American Meter Company, Inc.

ROCKWELL CAST IRON AND DOMESTIC METERS

Size	Working Press. Lbs.	Size Connections	Rating .60 Sp. Gas .5" Absorption	Cu. Ft. Per Rev. Proving Hand	Distance Center Line to Connections	Height	Shipping Weight
1	5-10	1, 1¼, 1½	275	2	7"	14⅜"	45½
2	10	1¼, 1½	415	5	8"	16 11/16"	67
175 curb box	5	1¼	175	2½	4½"	14 9/16"	37
2 curb box	10	1½	415	5	7½"	19¼"	70

ROCKWELL ALUMINUM DOMESTIC METERS

Size	Working Press. Lbs.	Size Connections	.5" Absorption .60 Sp. Gas Rating	Cu. Ft. per Rev. Proving Hand	Distance Center Line to Connections	Height	Shipping Weight
150	5	½, ¾, 1, 1¼	150	2	6"	11 9/32"	12
175	5-10*	½, ¾, 1, 1¼	175	2½	6"	12 11/16"	19½
	50	½, ¾, 1	175	2½	6"	13 7/16"	40
1	5	1, 1¼, 1½	275	2	7"	14⅜"	25
415	10	1¼, 1½	415	5	7"	14¾"	

* If requested on order

ROCKWELL INDUSTRIAL AND LARGE CAPACITY METERS

Size	Working Press. Lbs.	Size Connections	.5 absorption	.02 absorption	Cu. Ft. per Rev. Proving Hand	Length	Height	Shipping Weight
800	100	1½" FPT-45LT	800	1,600	5	16⅛"	22 27/32"	70
2½	75	2" FPT	950	2,000	10	20⅜"	25⅛"	212
	100	2" FPT	950	2,000	10	20¾"	25 15/16"	345
	200	2" FPT	950	2,000	10	20¾"	25 15/16"	345
	500	2" FPT	950	2,000	10	21¾"	26⅛"	476
	1,000	2" Series 60 Ring Joint Flange	950	2,000	10	30⅞"	29 7/16"	986
3	75	2" or 3" FPT	1,200	2,500	10	22½"	27 13/16"	282
	100	2" or 3" FPT	1,200	2,500	10	22¼"	28⅝"	424
	200	2" or 3" FPT	1,200	2,500	10	22¼"	28⅝"	424
	500	2" or 3" FPT	1,200	2,500	10	22⅞"	28¾"	550
4	75	3" or 4" FPT	2,250	5,000	10	27¼"	32⅞"	486
	100	3" or 4" FPT	2,250	5,000	10	28"	32 13/16"	680
	200	3" or 4" FPT	2,250	5,000	10	28"	32 13/16"	680
	500	3" or 4" FPT	2,250	5,000	10	29¼"	34¼"	1093
4½	75	4" FPT	3,500	7,000	10	33¼"	42 1/6"	690
5	50	4" FPT	5,000	10,000	100	40"	51⅛"	980

Rockwell Manufacturing Co.

INSTRUCTIONS FOR ACCURATE PROOF TESTING OF GAS METERS

To arrive at accurate results in proof-testing gas meters necessitates close attention to a great many details. Merely connecting the meter to a prover and passing a small quantity of air or gas through, without strict regard to the following rules, will result in an approximation only and is not a correct proof test.

To proof test a meter accurately the prover must be mathe-

matically correct, perfectly level, duly counterpoised and adjusted so as to give uniform pressure from top to bottom during the movement of the bell in the tank. Provers are commonly adjusted to throw a pressure of one and one-half inches water column. The liquid in the prover, the air or gas in the bell and also the meter to be proof tested must all be uniform in temperature with the air of the room in which the tests are to be made and all of these temperatures must be kept uniform during the entire test.

The meter or meters to be proof tested should be brought to the proving room at least five hours or if possible for a longer period before making tests, thereby giving them an opportunity to become adjusted to room temperature. When these conditions have been met, the test may proceed.

The inlet of the meter is connected to the prover hose by means of a suitable connection. The connections and meter are then tested for leaks by opening the outlet valve on the prover connections, placing the palm of the hand over the meter outlet, and then closing the valve. If the siphon gauge shows a drop in pressure, it is an indication of a leak in the connection or in the meter. The leak can be located by means of soapsuds.

Attach the proper check cap on the meter outlet and pass enough air from the prover through the meter to bring the test hand, while on the up run, directly over a division or mark on the proving circle.

Fill the prover bell and carefully adjust the zero scale reading by means of the prover slide valve. Open the valve on the connection and pass a sufficient volume from the prover through the meter to cause the test hand to make one full revolution. Exercise care to insure that the test hand is stopped exactly over the mark from which it started at the beginning of the test. The reading on the prover scale is noted and from these data the proof is determined. If the meter is to be proof tested at the open rate, the procedure is the same as with the check rate test with the exception that the meter outlet is unrestricted. The maximum rate at which the prover delivers air through the hose and connections to the meter at the open-rate test depends upon the capacity of the meter, pressure in the prover, and size of connections from the interior of the prover to the meter.

Differential Test

The differential test of meters at a definite check rate is the supplementary test which is used as a final check to determine the absence of avoidable internal friction or binds in meters before final proof. For this purpose the differential, which is the difference in pressure between the inlet and outlet of the meter, is indicated in inches of water on a sensitive draft gauge.

At a very low rate of flow the differential is produced primarily by internal friction. In a properly assembled meter this internal friction depends upon the flexibility of the diaphragms, the relative tightness of the stuffing boxes, and to a certain extent, upon the clearance between the moving parts. In some cases where heavier diaphragms or tighter packing of the stuffing boxes are specified, a slightly higher differential will result. Consequently, for any particular size of meter, the differential limits will depend upon the specifications.

Any increase in differential resulting from binds, excessive friction in the stuffing boxes, or stiff diaphragm leather should be eliminated before final proof. This precaution is of basic importance because if internal friction is reduced by wear after a meter is placed in service, the proof may be affected.

At low rates of flow, the differential between meter inlet and outlet pressures may be about 0.10 inches of water.

American Meter Company, Inc.

PERCENTAGE OF ERROR TABLE

	2 cubic feet passed by meter		5 cubic feet passed by meter		10 cubic feet passed by meter		20 cubic feet passed by meter	
	Prover	Error	Prover	Error	Prover	Error	Prover	Error
FAST	1.80	+11.11	4.50	+11.11	9.00	+11.11	18.00	+11.11
	1.81	+10.50	4.52	+10.62	9.05	+10.50	18.10	+10.50
	1.82	+ 9.89	4.55	+ 9.89	9.10	+ 9.89	18.20	+ 9.89
	1.83	+ 9.29	4.58	+ 9.17	9.15	+ 9.29	18.30	+ 9.29
	1.84	+ 8.70	4.60	+ 8.70	9.20	+ 8.70	18.40	+ 8.70
	1.85	+ 8.11	4.62	+ 8.20	9.25	+ 8.11	18.50	+ 8.11
	1.86	+ 7.53	4.65	+ 7.83	9.30	+ 7.53	18.60	+ 7.53
	1.87	+ 6.95	4.68	+ 6.84	9.35	+ 6.96	18.70	+ 6.95
	1.88	+ 6.38	4.70	+ 6.38	9.40	+ 6.38	18.80	+ 6.38
	1.89	+ 5.82	4.72	+ 5.93	9.45	+ 5.82	18.90	+ 5.82
	1.90	+ 5.26	4.75	+ 5.26	9.50	+ 5.26	19.00	+ 5.26
	1.91	+ 4.71	4.78	+ 4.60	9.55	+ 4.71	19.10	+ 4.71
	1.92	+ 4.17	4.80	+ 4.17	9.60	+ 4.17	19.20	+ 4.17
	1.93	+ 3.63	4.82	+ 3.73	9.65	+ 3.63	19.30	+ 3.63
	1.94	+ 3.09	4.85	+ 3.09	9.70	+ 3.09	19.40	+ 3.09
	1.95	+ 2.56	4.88	+ 2.46	9.75	+ 2.56	19.50	+ 2.56
	1.96	+ 2.04	4.90	+ 2.04	9.80	+ 2.04	19.60	+ 2.04
	1.97	+ 1.52	4.92	+ 1.63	9.85	+ 1.52	19.70	+ 1.52
	1.98	+ 1.01	4.95	+ 1.01	9.90	+ 1.01	19.80	+ 1.01
	1.99	+ 0.50	4.98	+ 0.40	9.95	+ 0.50	19.90	+ 0.50
Correct	2.00	0.00	5.00	0.00	10.00	0.00	20.00	0.00
SLOW	2.01	−0.50	5.02	−0.40	10.05	−0.50	20.10	−0.50
	2.02	−0.99	5.05	−0.99	10.10	−0.99	20.20	−0.99
	2.03	−1.48	5.08	−1.57	10.15	−1.48	20.30	−1.48
	2.04	−1.96	5.10	−1.96	10.20	−1.96	20.40	−1.96
	2.05	−2.44	5.12	−2.34	10.25	−2.44	20.50	−2.44
	2.06	−2.91	5.15	−2.91	10.30	−2.91	20.60	−2.91
	2.07	−3.38	5.18	−3.47	10.35	−3.38	20.70	−3.38
	2.08	−3.85	5.20	−3.85	10.40	−3.85	20.80	−3.85
	2.09	−4.31	5.22	−4.21	10.45	−4.31	20.90	−4.31
	2.10	−4.76	5.25	−4.76	10.50	−4.76	21.00	−4.76
	2.11	−5.21	5.28	−5.30	10.55	−5.21	21.10	−5.21
	2.12	−5.66	5.30	−5.66	10.60	−5.66	21.20	−5.66
	2.13	−6.10	5.32	−6.02	10.65	−6.10	21.30	−6.10
	2.14	−6.54	5.35	−6.54	10.70	−6.54	21.40	−6.54
	2.15	−6.98	5.38	−7.06	10.75	−6.98	21.50	−6.98
	2.16	−7.41	5.40	−7.41	10.80	−7.41	21.60	−7.41
	2.17	−7.83	5.42	−7.75	10.85	−7.83	21.70	−7.83
	2.18	−8.26	5.45	−8.26	10.90	−8.26	21.80	−8.26
	2.19	−8.68	5.48	−8.76	10.95	−8.68	21.90	−8.68
	2.20	−9.09	5.50	−9.09	11.00	−9.09	22.00	−9.09

CHECK RATE AND OPEN RATE FOR AMERICAN TINNED STEELCASE METERS

Rates are expressed in cubic feet an hour.

Meter type	Standard capacity rate, gas	Check rate at 20 percent of standard rate	Diameter of check-rate orifice in inches	Open rate, approximate, for air
2 B	65	13	0.11	100
3 B	90	18	0.12	140
5 B	150	30	0.16	240
10 B	300	60	0.24	480
20 B	450	90	0.30	720
30 B	600	120	0.35	960
60 B	1300	260	0.52	2100
100 B	1800	360	0.62	2900
200 B	3200	640	0.81	5100
5 M	210	42	0.20	340
10 M	400	80	0.28	640
30 M	900	180	0.44	1400
60 M	1600	320	0.58	2600
5 A	175	35	0.18	280
10 A	375	75	0.27	600
20 A	600	120	0.35	960
30 A	875	175	0.43	1400
60 A	1500	300	0.56	2400
150 A	3400	680	0.85	5440
6 C	600	120	0.35	960
11 C	1100	220	0.49	1800
25 C	2500	500	0.73	4000
40 C	4000	800	0.92	6400
60 C	6000	1200	1.12	9600

The approximate diameters of the orifices are based on the check rate being 20 percent of the standard capacity. Air is used for testing. The pressure at the inlet of the meter is 1.5 inches of water and the thickness of the cap is 0.0625 inch. The approximate open rate is based on the assumption that air is used for testing and the pressure at the inlet of the meter is about 1.5 inches of water.

American Meter Company, Inc.

SPECIFICATIONS OF SPRAGUE GAS METERS

Size	Dimensions: Center of Connections	Height	Front to Back	Width	Proving Head	Teeth in Top Bracket	Cu. Ft. Per Rev.	Capacities* (W.C. Diff.): ½″	1″	1.7″ or 1 oz.	Aluminum Weight Lbs.	Cast Iron Weight Lbs.	Size Pipe Connections Inches
No. 1A	6″	13½″	7⅞″	9 7/16″	2 ft.	15	.133	175	241	315	13	29½	¾, 1 & 1¼
No. 240	6″	13⅞″	7⅛″	9 7/16″	2 ft.	15	.133	240	330	432	13	—	¾, 1 & 1¼
No. 2	7 3/16″	15½″	8¾″	10¾″	5 ft.	24	.208	305	435	575	20	45	1 & 1¼
No. 3	6 25/32″	17 3/16″	9 13/16″	12⅛″	5 ft.	17	.294	400	540	654	25	52½	1½ & 1½
No. 4	10″	22½″	13⅞″	15⅞″	5 ft.	†16	.625	675	900	1250	55	132	1¼ & 1½
No. 5A	10⅞″	26 9/16″	15½″	18″	20 ft.	17	1.177	1000	1490	1850	78	190	2

*5″ inlet pressure, 0.60 Sp. G. †Double worm.

SPRAGUE COMBINATION METER AND REGULATORS

The combination meter and regulator consists of a standard meter with the regulator built as an integral part of the top. The unit has the following advantages in the field and in the shop: (1) The regulator and meter can be installed in an area no greater than that occupied by a conventional low-pressure setup, (2) a considerable amount of space can be saved in storage areas in the shop and on transportation units, (3) fewer fittings are necessary resulting in a more rigid installation and (4) the reduction in the quantity of fittings eliminates some of the sources of leaks, and the added rigidity reduces to some extent the possibility of leakage.

In group installations the combination provides individual pressure control for each consumer regardless of the length of the house line or whether the connected load is large or small. In the advent of trouble call it is only necessary to shut off the service to the customer involved. The other consumers are in no way affected as would be the case in a conventional regulator and header set-up. The benefits of this feature are twofold: (1) individual pressure control, and (2) localization of trouble.

With the combination unit the meter number serves as an identification for both meter and regulator. Inspection and servicing of the regulator becomes part of the meter repair at the periodic changes. This can be accomplished at a cost only slightly higher than an ordinary meter repair.

Combination Meters and Regulators are made presently in Sizes 1A and 2.

CAST IRON AND ALUMINUM CASES

Meter cases are now made in both cast iron and aluminum. The cast iron case has been standard for many years. With the event of new types of alloys and requests for light-weight meters having all the advantages of cast iron, the aluminum alloy meter has been brought forth to meet the necessary specifications. The advantages of the aluminum case meter are, freedom from rust, requires no paint, light to handle, no fire hazard, and all parts being interchangeable with older models.

MEASUREMENT—AT HIGH PRESSURE

Gas meters always measure the gas at line pressure. It is not always practicable to reduce the pressure and measure the gas at low pressure. In many instances it would be necessary to compress the gas again to transmit it to the point of consumption.

Meters for high pressure service have the same measuring mechanism as those employed for low pressure. The only difference is in the strength of the case.

If the line pressure does not remain constant, it is necessary to equip the meter with a recording volume and pressure gauge in order to arrive at the correct base or selling pressure. The correct volume is computed from the guage chart and a pressure table.

If the line pressure remains constant, a pressure and volume gauge is not necessary. The correct pressure factor may be taken from the table and applied directly to the meter reading.

The generally accepted average atmospheric pressure is 14.4 pounds. Gauge pressure is the difference between the absolute pressure and the atmospheric pressure, viz., the absolute pressure equals the atmospheric pressure plus guage pressure. Absolute pressure must be used in all gas calculations involving the gas laws.

The method of converting volume measured at high pressure to volume at a base or selling pressure is as follows:

Meter Reading	215,512 cu. ft.
Atmospheric pressure	14.4 pounds per sq. in.
Base pressure	4 ounces
Gauge pressure	45 pounds per sq. in.

In the table under "Base pressure 4 ounces" observe the constant for 45 pounds gauge pressure. It is found to be 4.055. Multiply the meter reading by this constant to obtain the volume measured at the selling pressure, or 4.055 x 215,512 = 873,901 cu. ft.

If the pressure varies, it is necessary to employ a recording volume and pressure gauge. An average pressure for the volume measured is calculated from the gauge chart. This average pressure is then interpolated in table of pressure factors and the calculations from this point are identical to those employed for a constant pressure.

Sprague Meter Company.

CRITICAL FLOW ORIFICE PROVERS

The critical flow orifice prover may be used for testing positive displacement meters at a pressure of 15 pounds gauge or more by passing gas or air through the meter and the orifice, and discharging it into the atmosphere.

If the proof of the meter does not change with changes in pressure (it should not) the time required for a full circle reading of the proving hand of the index will be the same for any particular orifice and any kind of gas, regardless of variations in pressure.

To test a meter under working pressure conditions, the prover is attached to a connection close to the meter outlet.

The orifice of proper size for testing the meter should be selected from a table furnished by the manufacturer showing the approximate time required for the passage of one cubic foot of air. A .500-inch orifice should be used for testing a meter at a rate of 4000 cu. ft. (index reading) an hour. A .250-inch orifice may be used for the low test rate.

On account of the small size of the orifice used, it is not practicable to calculate the standard air time by the measurement of the diameter of the orifice. It is always determined by test and is stamped on the outlet side of the disc by the manufacturer.

The "gas time" for a test with any orifice depends upon the size of the orifice, the ratio of specific heats of the gas, the temperature of the specific gravity.

Tables to simplify the calculations in connection with the testing of meters with critical flow orifice provers are furnished by the manufacturer.

See American Meter Company Bulletin E-8.

PRESSURE FACTORS FOR HIGH PRESSURE MEASUREMENT

Gauge Pressure Pounds	Base Pressure, Pounds Absolute 14.65 (4 oz.)	14.9 (8 oz.)	15.025 (10 oz.)	16.4 (2 lb.)	Gauge Pressure Pounds	Base Pressure, Pounds Absolute 14.65 (4 oz.)	14.9 (8 oz.)	15.025 (10 oz.)	16.4 (2 lb.)
0	0.983	0.966	0.958	0.878	38	3.577	3.517	3.488	3.195
1	1.051	1.034	1.025	0.939	39	3.645	3.584	3.554	3.256
2	1.119	1.101	1.092	1.000	40	3.713	3.651	3.621	3.317
3	1.188	1.168	1.158	1.061	41	3.782	3.718	3.687	3.378
4	1.256	1.235	1.225	1.122	42	3.849	3.785	3.754	3.439
5	1.324	1.302	1.291	1.183	43	3.918	3.852	3.820	3.500
6	1.392	1.369	1.358	1.244	44	3.986	3.919	3.887	3.561
7	1.461	1.436	1.424	1.305	45	4.055	3.987	3.953	3.622
8	1.529	1.503	1.491	1.366	46	4.123	4.054	4.020	3.683
9	1.597	1.570	1.557	1.427	47	4.191	4.121	4.087	3.744
10	1.666	1.638	1.624	1.488	48	4.259	4.188	4.153	3.805
11	1.734	1.705	1.691	1.549	49	4.328	4.255	4.220	3.866
12	1.802	1.772	1.757	1.610	50	4.396	4.322	4.286	3.927
13	1.870	1.839	1.824	1.671	51	4.464	4.389	4.353	3.988
14	1.939	1.906	1.890	1.732	52	4.532	4.456	4.419	4.049
15	2.007	1.973	1.957	1.793	53	4.601	4.523	4.486	4.110
16	2.075	2.040	2.023	1.854	54	4.669	4.591	4.552	4.171
17	2.143	2.107	2.090	1.915	55	4.737	4.658	4.619	4.232
18	2.212	2.174	2.156	1.976	56	4.805	4.725	4.686	4.293
19	2.280	2.242	2.223	2.037	57	4.874	4.792	4.752	4.354
20	2.348	2.309	2.290	2.098	58	4.942	4.859	4.819	4.415
21	2.416	2.376	2.356	2.159	59	5.010	4.926	4.885	4.476
22	2.485	2.443	2.423	2.220	60	5.078	4.993	4.952	4.537
23	2.553	2.510	2.489	2.280	61	5.147	5.060	5.018	4.598
24	2.621	2.577	2.556	2.341	62	5.215	5.128	5.085	4.659
25	2.689	2.644	2.622	2.402	63	5.283	5.195	5.151	4.720
26	2.758	2.711	2.689	2.463	64	5.352	5.262	5.218	4.780
27	2.826	2.779	2.755	2.524	65	5.420	5.329	5.285	4.841
28	2.894	2.846	2.822	2.585	66	5.488	5.396	5.351	4.902
29	2.962	2.913	2.889	2.646	67	5.556	5.463	5.418	4.963
30	3.031	2.980	2.955	2.707	68	5.625	5.530	5.484	5.024
31	3.099	3.047	3.022	2.768	69	5.693	5.597	5.551	5.085
32	3.167	3.114	3.088	2.829	70	5.761	5.664	5.617	5.146
33	3.235	3.181	3.155	2.890	71	5.829	5.732	5.684	5.207
34	3.304	3.248	3.221	2.951	72	5.898	5.799	5.750	5.268
35	3.372	3.315	3.288	3.012	73	5.966	5.866	5.817	5.329
36	3.440	3.383	3.354	3.073	74	6.034	5.933	5.884	5.390
37	3.509	3.450	3.421	3.134	75	6.102	6.000	5.950	5.451

METHOD FOR DETERMINING REGULATOR CAPACITIES

A study of the various equations now in use for computing regulator capacities reveals the following seem to be the most practical:

(1) Where the flow is below critical velocity (regulator outlet absolute pressure being more than one half of the regulator inlet absolute pressure): $Q = K\sqrt{h\,p_o}$

(2) Where the flow is above critical velocity (regulator outlet absolute pressure being less than one half of regulator inlet absolute pressure): $Q = \frac{1}{2} KP_1$

Where,

Q = M Cu. Ft. per hour of .65 Sp. Gr. Gas at a base press. of 14.73 Lbs. per Sq. In. absolute

h = Drop in pressure across regulator in Lbs. per Sq. In.

P_o = Absolute outlet pressure in Lbs. per Sq. In.

P_1 = Absolute inlet pressure in Lbs. per Sq. In.

K = Constant, depending on regulator valve size and characteristics

For convenience, these equations are transposed as follows:

$$Q = K \times \text{Flow Factor}$$

Graphic Charts Figures 1, 2, 3, & 4 have been prepared whereby flow factors may be read directly, depending upon the regulator inlet and outlet pressures.

The "Flow Factor" (shown on bottom scale) is equal to $\sqrt{hp_o}$, for conditions outlined under equation (1); and is equal to $\frac{1}{2} P_1$, for conditions outlined under equation (2). These flow factors when multiplied by factor "K" (in table) equal the recommended maximum regulator capacity.

In attempting to determine "K" factors for practical use for the different regulators in common use, it is necessary to make several compromises and assumptions which are briefly stated as follows:

(1) It is interpreted that the maximum capacity of a regulator is that quantity of gas which a regulator will deliver at a given pressure drop between its inlet and outlet flanges; that is, the regulator body is considered the unit rather than only the regulator valves or any part of the setting.

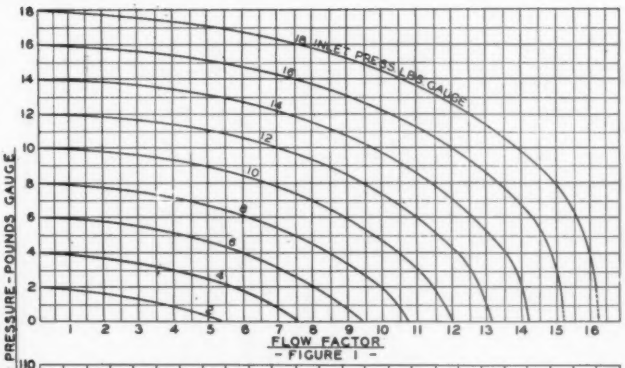
(2) In developing practical "K" factors for the different regulators, it is known that some regulators have greater valve opening areas than the area of the regulator outlet pipe opening. In such cases, the capacity should be reduced to an amount equivalent to a valve opening area equal to approximately 60 per cent of the regulator outlet pipe opening cross sectional area.

(3) These capacity data are based entirely on the capacity of the regulator main body and do not take into account variations in outlet pressure resulting from other causes, such as friction, lack of operative power, etc., which are rather common in the older type of regulator.

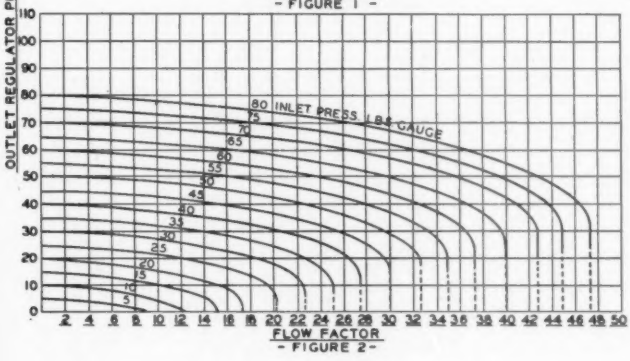
The table sets forth practical "average values" for K, which are believed to be accurate and safe for the purpose intended. In most instances they are as accurate as many of the other variables involved, such as the estimated inlet and outlet pressures, etc. Where more accurate values of "K" are available, such as those furnished by regulator manufacturers, obtained from special tests, etc., they may be substituted for those in the table and inserted in the blank spaces provided.

There may be instances where special regulators are in use and it is desired to obtain their approximate capacity. This may be done by determining the valve opening area in terms of square inches and using a "K" factor of 1.00 for each square inch, providing this area is no greater than approximately 60 per cent of the regulator outlet pipe opening. If the valve opening area is greater than 60 per cent of the outlet pipe opening, the valve opening area above this amount should be ignored. The approximate regulator capacity is then equal to "K" x Flow Factor, in the same manner as though the "K" were taken from the table.

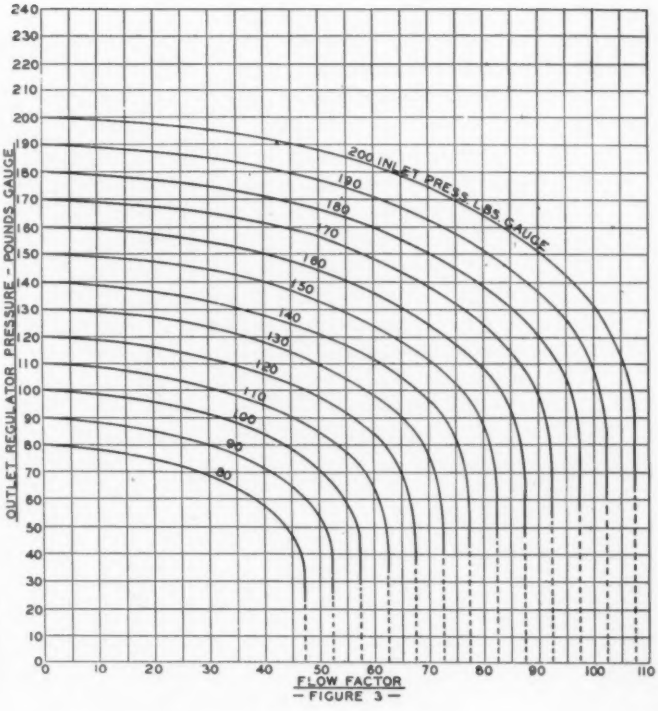
From Columbia Gas System Engineering Corp.



- FIGURE 1 -



- FIGURE 2 -



- FIGURE 3 -

To determine Maximum Capacity of Regulator:

(1) Locate outlet pressure on left margin of graph
(2) Trace horizontally to estimated minimum inlet pressure
(3) Trace vertically down and read "Flow Factor" on bottom scale
(4) Maximum hourly capacity = Flow Factor x "K" factor

Example:

Assume—A 6" Regulator, 25 Lb. Outlet Gauge Pressure, and an estimated minimum inlet Gauge Pressure of 40 Lb.

Then —From graph (Figure 2) Flow Factor = 24.5, and from table "K" Factor = 16.5
Maximum Regulator Capacity = 24.5 x 16.5 or 400 M. Cubic Feet per Hour

To determine size regulator required when the quantity and pressure conditions are known:

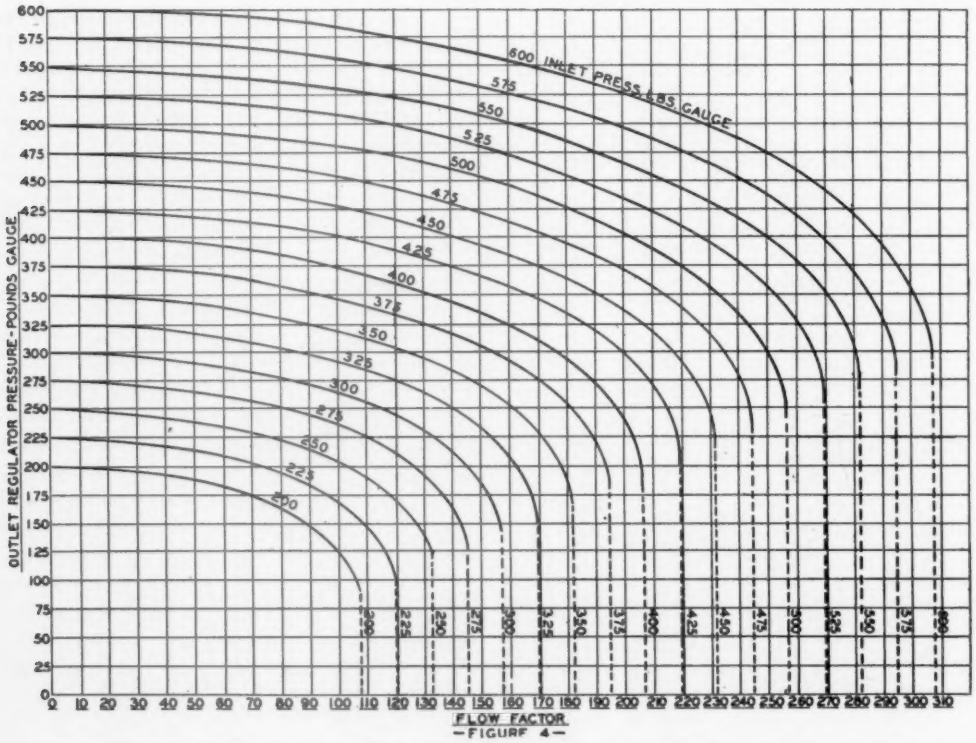
Example:

Assume—A maximum hourly rate of flow 100 M. Cu. Ft. per Hour, an Outlet Pressure of 100 Lb., and an estimated minimum inlet Pressure of 250 Lb.

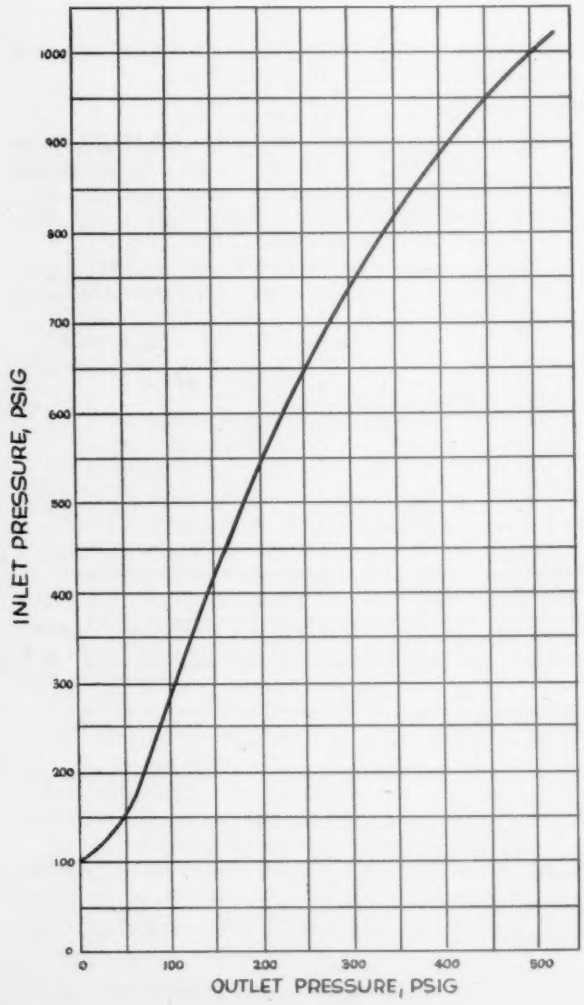
Then —From Graph (Figure 4), Flow Factor = 133, therefore "K" Factor required = 100 ÷ 133 or .75
It will be noted from table shown that a 2" regulator having 1" balanced valves will have ample capacity.

Practical K Factors For Use In Determining Regulator Capacities

Size Regulator	K Factors "Average Values"
2" (¾" Balanced Valves)	.43
2" (1" " ")	1.4
2" (Std. " ")	1.9
3" (" " ")	4.2
4" (" " ")	7.5
6" (" " ")	16.5
8" (" " ")	27.5
10" (" " ")	42.0
12" (" " ")	61.0



—FIGURE 4—



GUIDE FOR DETERMINING PRACTICAL PRESSURE CUT FOR SINGLE GAS REGULATOR

And Number of Cuts Required for a Station

Explanatory

Case A:

To determine the practical pressure cut for a 700 psig inlet pressure.

1—Locate 700 psig inlet pressure on the left scale of the graph.

2—Trace horizontally to the right to the curve and then trace vertically downward to the bottom scale. Read outlet pressure of 280 psig.

Case B:

To determine the number of cuts required for a station where the inlet pressure is 700 psig and the desired outlet pressure is to be 20 psig.

First cut—700 psig to 280 psig.
Second cut—280 psig to 100 psig.
Third cut—100 psig to 20 psig.

From Columbia Gas System Engineering Corp.

DIMENSION DATA ON TELESCOPIC WET SEAL GAS HOLDERS

Capacity Thousand Cubic Feet	Number of Lifts	Tank Dimensions Diam.	Tank Dimensions Height	Number of Columns	Pressure Inflated with Air — LIFTS 1st	2nd	3rd	4th	All	Usual Conn. Diam.	FOUNDATION Diameter	Excavation Cu.Yds.	Concrete Cu.Yds.	Water Load per Sq. Ft. on Bottom	Water To Fill Tank Gallons
5	One	25'-0"	12'-6"	4	4.8"				4.8"	6"	27'-6"	69	54	767	45,000
10	One	32'-0"	15'-6"	4	5.1"				5.1"	6"	34'-6"	84	69	955	91,700
15	One	37'-0"	17'-0"	4	4.5"				4.5"	10"	39'-6"	96	81	1048	134,700
20	One	40'-6"	18'-6"	5	4.6"				4.6"	10"	43'-0"	105	90	1142	175,900
25	One	42'-0"	21'-3"	5	4.8"				4.8"	10"	44'-6"	109	94	1315	207,400
30	One	44'-6"	22'-6"	6	4.8"				4.8"	12"	47'-0"	134	108	1395	258,800
40	One	50'-6"	23'-0"	6	5.1"				5.1"	12"	53'-0"	164	138	1422	340,700
50	One	55'-6"	23'-8"	6	4.8"				4.8"	12"	58'-0"	168	142	1465	424,300
60	One	59'-6"	24'-6"	6	4.6"				4.6"	12"	62'-0"	189	155	1533	505,000
75	One	64'-0"	26'-3"	8	4.6"				4.6"	12"	66'-6"	198	172	1628	625,700
100	One	71'-3"	28'-0"	8	4.4"				4.4"	12"	73'-9"	226	200	1735	828,200
125	One	79'-3"	28'-0"	9	4.5"				4.5"	12"	81'-9"	259	233	1735	840,700
75	Two	50'-6"	23'-0"	9	5.6"				9.7"	12"	53'-0"	165	139	1422	340,700
100	Two	57'-5"	23'-10"	9	5.4"				9.1"	12"	59'-11"	190	164	1478	457,000
125	Two	62'-0"	25'-6"	9	5.9"				10.0"	12"	64'-6"	206	180	1582	570,200
150	Two	66'-6"	26'-0"	9	5.6"				9.4"	16"	69'-0"	248	208	1610	669,000
200	Two	73'-2"	28'-3"	9	5.2"				8.8"	16"	75'-8"	278	238	1752	882,000
250	Two	79'-8"	29'-9"	10	5.5"				9.1"	16"	82'-2"	308	268	1848	1,101,100
300	Two	84'-3"	31'-4"	10	5.5"				9.1"	16"	86'-9"	332	292	1945	1,294,900
400	Two	93'-3"	34'-0"	10	6.1"				9.9"	24"	95'-9"	403	348	2110	1,729,300
500	Two	102'-0"	35'-2"	12	5.4"				8.9"	24"	104'-6"	455	400	2185	2,134,300
300	Three	75'-0"	28'-3"	9	5.0"	8.3"			11.2"	16"	78'-0"	316	276	1752	925,300
400	Three	80'-0"	32'-4"	10	5.5"	9.1"			12.3"	24"	83'-0"	364	309	2010	1,206,100
500	Three	93'-9"	28'-10"	10	5.2"	8.2"			10.8"	24"	96'-9"	440	385	1788	1,475,600
600	Three	95'-4½"	34'-0"	10	6.1"	9.8"			13.0"	24"	98'-4½"	450	395	2110	1,805,000
750	Three	104'-7"	35'-0"	12	6.0"	9.6"			12.6"	24"	107'-7"	504	449	2170	2,240,600
1,000	Three	118'-6"	35'-9"	14	5.9"	9.5"			12.7"	24"	121'-6"	605	550	2220	2,928,700
1,500	Three	142'-5"	36'-3"	16	5.5"	8.7"			11.4"	30"	145'-5"	857	754	2250	4,293,700
1,000	Four	105'-0"	35'-0"	12	7.2"	11.1"	14.7"		17.9"	30"	108'-0"	605	502	2185	2,245,000
1,500	Four	136'-6"	30'-10"	14	5.5"	8.5"	11.2"		13.6"	30"	139'-6"	843	740	1915	3,350,000
2,000	Four	145'-5"	35'-8"	16	5.9"	8.6"	11.1"		13.0"	36"	148'-5"	976	863	2215	4,411,300
3,000	Four	175'-0"	36'-3"	18	5.5"	8.4"	11.0"		13.3"	36"	178'-0"	1253	1140	2250	6,477,000
5,000	Five	204'-4"	35'-9"	22	5.2"	7.5"	9.6"	11.7"	13.5"	36"	207'-4"	1613	1500	2220	8,709,700
6,000	Five	210'-2"	40'-6"	22	5.8"	8.1"	10.4"	12.5"	14.3"	42"	213'-2"	1739	1590	2520	10,477,300
8,000	Five	240'-9"	40'-4"	24	6.0"	8.3"	10.5"	12.7"	14.5"	42"	243'-9"	2129	1980	2500	13,670,800
10,000	Five	276'-6"	38'-2"	28	5.1"	7.0"	8.7"	10.4"	14.7"	42"	279'-6"	2639	2490	2375	17,031,300

NATIONAL API
PLAIN END PIPE FOR OIL, GAS, AND GASOLINE LINES

Ends Finished for Specified Couplers or Welded Joints

This table is intended for the determination of sizes and thicknesses for long lines. It includes all sizes listed in American Petroleum Institute Line Pipe Specification No. 5-L, tenth edition.

"R" indicates regular sizes and weights, which can be furnished most readily; sizes and weights indicated by "L" are not regularly available for immediate shipment. It may not always be possible to consider the manufacture of these items in small quantities.

The permissible variation in weight for all the pipe is in accordance with the API Specification. The weights indicated by the letter "R" will not vary more than 3½ per cent under or 10 per cent over that specified and the lighter weights (indicated by the letter "L") will not vary more than 5 per cent under or 10 per cent over that specified.

The working pressures with safety factors are given for Grade A seamless and for Grade B seamless. To obtain the working pressure for other factors of safety, multiply the pressure shown by the given safety factor and divide by the safety factor desired.

Barlow's Formula was used in calculating the listed working, test, and bursting pressures:

$$P = 2f\frac{t}{D}$$

D = outside diameter of pipe—inches;
t = nominal thickness of wall—inches;
P = internal pressure—pounds per square inch;
f = fiber stress—pounds per square inch.

When plain end pipe is ordered beveled for welding, caulking, or other purposes, it is understood that the angle specified is to be measured from a line drawn perpendicular to the axis of the pipe, which means that a greater amount of material is removed with a 60-degree angle than with a 30-degree angle. Unless otherwise specified, pipe ordered for welding will be beveled 30 degrees.

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Size: outside diameter	Weight per foot plain ends	Wall thickness		Net tons per mile	[1] Ultimate bursting pressures		Test pressures		[1] Working pressures					
									Grade A seamless			Grade B seamless		
									Factor of safety					
		Fraction	Decimal of inch		Grade A seamless	Grade B seamless	Grade A seamless	Grade B seamless	3	4	5	3	4	5
Ins.	Lbs.				PSI		PSI		PSI			PSI		
3½	4.51 L	⅛	.125	11.906	3570	4290	1300	1500	1190	890	710	1430	1070	860
3½	5.58 L	5/32	.156	14.731	4460	5360	1600	1900	1490	1120	890	1790	1340	1070
3½	6.63 R	3/16	.188	17.503	5380	6430	1900	2200	1790	1340	1070	2140	1610	1290
3½	7.58 R	..	.216	20.011	6170	7410	2200	2500	2080	1540	1230	2470	1850	1480
3½	8.68 R	¼	.250	22.915	7140	8570	2500	2500	2380	1780	1430	2860	2140	1710
3½	9.67 R	9/32	.281	25.529	8030	9630	2500	2500	2680	2010	1610	3210	2410	1930
3½	10.25 R	..	.300	27.060	8570	10290	2500	2500	2860	2140	1710	3430	2570	2060
4	5.17 L	⅛	.125	13.649	3120	3750	1100	1300	1040	780	630	1250	940	750
4	6.41 L	5/32	.156	16.922	3900	4690	1400	1600	1300	980	780	1560	1170	940
4	7.63 L	3/16	.188	20.143	4690	5630	1700	2000	1560	1170	940	1880	1410	1130
4	9.11 L	..	.226	24.050	5650	6780	2000	2400	1880	1410	1130	2260	1700	1360
4	10.01 L	¼	.250	26.426	6250	7500	2200	2500	2080	1560	1250	2500	1880	1500
4	11.17 L	9/32	.281	29.489	7030	8440	2500	2500	2340	1760	1410	2810	2110	1690
4	12.51 L	..	.318	33.026	7950	9540	2500	2500	2650	1990	1590	3180	2390	1910
4½	5.84 L	⅛	.125	15.418	2780	3330	1000	1200	930	700	560	1110	830	670
4½	7.25 L	5/32	.156	19.140	3470	4160	1200	1500	1160	870	690	1390	1040	830
4½	8.64 R	3/16	.188	22.810	4170	5000	1500	1800	1390	1040	830	1670	1250	1000
4½	10.00 R	7/32	.219	26.400	4870	5840	1700	2000	1620	1220	970	1940	1460	1170
4½	10.79 R	..	.237	28.486	5270	6320	1900	2200	1760	1320	1050	2110	1580	1260
4½	11.35 R	¼	.250	29.964	5560	6670	2000	2300	1850	1390	1110	2220	1670	1330
4½	12.67 R	9/32	.281	33.449	6250	7500	2200	2500	2080	1560	1250	2500	1880	1500
4½	13.98 R	5/16	.312	36.907	6940	8330	2500	2500	2310	1740	1390	2780	2080	1670
4½	14.98 R	..	.337	39.547	7490	8990	2500	2500	2500	1870	1500	3000	2250	1800
5 9/16	9.02 L	5/32	.156	23.813	2810	3370	1000	1200	940	700	560	1120	840	670
5 9/16	10.76 L	3/16	.188	28.406	3370	4040	1200	1400	1120	840	670	1350	1010	810
5 9/16	12.49 L	7/32	.219	32.974	3930	4720	1400	1700	1310	980	790	1570	1180	940
5 9/16	14.62 L	..	.258	38.597	4640	5570	1700	1900	1550	1160	930	1860	1390	1110
5 9/16	15.87 L	9/32	.281	41.897	5050	6060	1800	2100	1680	1260	1010	2020	1520	1210
5 9/16	17.52 L	5/16	.312	46.253	5620	6740	2000	2400	1870	1400	1120	2250	1690	1350
5 9/16	19.16 L	11/32	.344	50.582	6180	7410	2200	2500	2060	1540	1240	2470	1850	1480
5 9/16	20.78 L	⅜	.375	54.859	6740	8090	2400	2500	2250	1680	1350	2700	2020	1620
6 5/8	12.89 R	3/16	.188	34.030	2830	3400	1000	1200	940	710	570	1130	850	680
6 5/8	14.97 R	7/32	.219	39.521	3300	3960	1200	1400	1100	830	660	1320	990	790
6 5/8	17.02 R	¼	.250	44.933	3770	4530	1400	1600	1260	940	750	1510	1130	910
6 5/8	18.97 R	..	.280	50.081	4230	5070	1500	1800	1410	1060	850	1690	1270	1010
6 5/8	21.07 R	5/16	.312	55.625	4720	5660	1700	2000	1570	1180	940	1890	1420	1130

[1] Values indicated are non-API.

Size: outside diameter	Weight per foot plain ends	Wall thickness		Net tons per mile	[1] Ultimate bursting pressures		Test pressures		[1] Working pressures					
									Grade A seamless			Grade B seamless		
									Factor of safety					
		Fraction	Decimal of inch		Grade A seamless	Grade B seamless	Grade A seamless	Grade B seamless	3	4	5	3	4	5
Ins.	Lbs.				PSI		PSI		PSI			PSI		
6⅝	23.06 R	11/32	.344	60.878	5190	6230	1900	2200	1730	1300	1040	2080	1560	1250
6⅝	25.03 R	3/8	.375	66.079	5660	6790	2000	2400	1890	1420	1130	2260	1700	1360
6⅝	28.57 R	..	.432	75.425	6520	7820	2300	2500	2170	1630	1300	2610	1960	1560
8⅝	16.90 R	3/16	.188	44.616	2170	2610	800	900	720	540	430	870	650	520
8⅝	19.64 R	7/32	.219	51.850	2540	3040	900	1100	850	630	510	1010	760	610
8⅝	22.36 R	1/4	.250	59.030	2900	3480	1000	1200	970	720	580	1160	870	700
8⅝	24.70 R	..	.277	65.208	3210	3850	1200	1300	1070	800	640	1280	960	770
8⅝	27.74 R	5/16	.312	73.234	3620	4350	1300	1500	1210	910	720	1450	1090	870
8⅝	28.55 R	..	.322	75.372	3730	4480	1300	1600	1240	930	750	1490	1120	900
8⅝	30.40 R	11/32	.344	80.256	3990	4780	1400	1700	1330	1000	800	1590	1200	960
8⅝	33.04 R	3/8	.375	87.228	4350	5220	1600	1800	1450	1090	870	1740	1300	1040
8⅝	38.26 R	7/16	.438	101.006	5070	6090	1800	2100	1690	1270	1010	2030	1520	1220
8⅝	43.39 R	1/2	.500	114.550	5800	6960	2100	2400	1930	1450	1160	2320	1740	1390
10¾	21.15 L	3/16	.188	55.836	1750	2100	650	750	580	440	350	700	520	420
10¾	24.60 R	7/32	.219	64.944	2030	2440	750	850	680	510	410	810	610	490
10¾	28.04 R	1/4	.250	74.026	2330	2790	850	1000	780	580	470	930	700	560
10¾	31.20 R	..	.279	82.368	2600	3110	1000	1200	870	650	520	1040	780	620
10¾	34.24 R	..	.307	90.394	2880	3430	1000	1200	950	710	570	1140	860	690
10¾	38.20 R	11/32	.344	100.848	3200	3840	1100	1300	1070	800	640	1280	960	770
10¾	40.48 R	..	.365	106.867	3400	4070	1200	1400	1130	850	680	1360	1020	810
10¾	48.19 R	7/16	.438	127.222	4070	4880	1500	1700	1380	1020	810	1630	1220	980
10¾	54.74 R	1/2	.500	144.514	4650	5580	1700	2000	1550	1160	930	1860	1400	1120
12¾	29.28 L	7/32	.219	77.299	1720	2060	600	700	570	430	340	690	510	410
12¾	33.38 R	1/4	.250	88.123	1960	2350	700	800	650	490	390	780	580	470
12¾	37.45 R	9/32	.281	98.868	2210	2650	800	950	740	550	440	880	660	530
12¾	41.51 R	5/16	.312	109.586	2450	2940	900	1000	820	610	490	980	740	590
12¾	43.77 R	..	.330	115.553	2580	3110	1000	1200	860	650	520	1040	780	620
12¾	45.55 R	11/32	.344	120.252	2700	3240	1000	1200	900	670	540	1080	810	650
12¾	49.56 R	3/8	.375	130.838	2940	3530	1100	1200	980	740	590	1180	880	710
12¾	57.53 R	7/16	.438	151.879	3430	4120	1200	1400	1140	860	690	1370	1030	820
12¾	65.42 R	1/2	.500	172.709	3920	4710	1400	1600	1310	980	780	1570	1180	940
14	36.71 L	1/4	.250	96.914	1790	2140	650	750	600	450	360	710	540	430
14	41.21 L	9/32	.281	108.794	2010	2410	700	850	670	500	400	800	600	480
14	45.68 R	5/16	.312	120.595	2230	2680	800	950	740	560	450	890	670	540
14	50.14 R	11/32	.344	132.370	2460	2950	900	1000	820	610	490	980	740	590
14	54.57 R	3/8	.375	144.065	2680	3210	950	1100	890	670	540	1070	800	640
14	63.37 R	7/16	.438	167.297	3130	3750	1100	1300	1040	780	630	1250	940	750
14	72.09 R	1/2	.500	190.318	3570	4290	1300	1500	1190	890	710	1430	1070	860
16	42.05 L	1/4	.250	111.012	1560	1880	550	650	520	390	310	630	470	380
16	47.22 L	9/32	.281	124.661	1760	2110	650	750	590	440	350	700	530	420
16	52.36 R	5/16	.312	138.230	1950	2340	700	800	650	490	390	780	590	470
16	57.48 R	11/32	.344	151.747	2150	2580	750	900	720	540	430	860	640	520
16	62.58 R	3/8	.375	165.211	2340	2810	850	1000	780	590	470	940	700	560
16	72.72 R	7/16	.438	191.981	2730	3280	1000	1100	910	680	550	1090	820	660
16	82.77 R	1/2	.500	218.513	3130	3750	1100	1300	1040	780	630	1250	940	740
18	47.39 L	1/4	.250	125.110	1390	1670	500	600	460	350	280	560	420	330
18	53.22 L	9/32	.281	140.501	1560	1880	550	650	520	390	310	630	470	380
18	59.03 R	5/16	.312	155.839	1740	2080	600	750	580	430	350	690	520	420
18	64.82 R	11/32	.344	171.125	1910	2290	700	800	640	480	380	760	570	460
18	70.59 R	3/8	.375	186.358	2080	2500	750	900	690	520	420	830	630	500
18	82.06 R	7/16	.438	216.638	2430	2920	900	1000	810	610	490	970	730	580
18	93.45 R	1/2	.500	246.708	2780	3330	1000	1200	930	690	560	1110	830	670
20	52.73 L	1/4	.250	139.207	1250	1500	450	500	420	310	250	500	380	300
20	59.23 L	9/32	.281	156.367	1410	1690	500	600	470	350	280	560	420	340
20	65.71 R	5/16	.312	173.474	1560	1880	550	650	520	390	310	630	470	380
20	72.16 R	11/32	.344	190.502	1720	2060	600	700	570	430	340	690	520	410
20	78.60 R	3/8	.375	207.504	1880	2250	700	800	630	470	380	750	560	450
20	91.41 R	7/16	.438	241.322	2190	2630	800	900	730	550	440	880	660	530
20	104.13 R	1/2	.500	274.903	2500	3000	900	1000	830	630	500	1000	750	600
22	72.38 L	5/16	.312	191.083	1420	1700	500	600	470	380	280	570	430	340
22	79.51 L	11/32	.344	209.906	1560	1880	550	650	520	390	310	630	470	380
22	86.61 L	3/8	.375	228.650	1700	2050	600	700	570	430	340	680	510	410
22	100.75 L	7/16	.438	265.980	1990	2390	700	850	660	500	400	800	600	480
22	114.81 L	1/2	.500	303.098	2270	2730	800	950	760	570	450	910	680	550
24	79.08 L	5/16	.312	208.718	1300	1560	450	550	430	330	260	520	390	310
24	86.85 L	11/32	.344	229.284	1430	1720	500	600	480	360	290	570	430	340
24	94.62 L	3/8	.375	249.797	1560	1880	550	650	520	390	310	630	470	380
24	110.10 L	7/16	.438	290.664	1820	2190	650	750	610	460	360	730	550	440
24	125.49 L	1/2	.500	331.294	2080	2500	750	850	690	520	420	830	620	500
[2]26	85.73 L	5/16	.312	226.33	1200	1440	450	500	400	300	240	480	360	290
[2]26	102.63 L	3/8	.375	270.94	1440	1730	500	600	480	360	290	580	430	350
[2]26	119.44 L	7/16	.438	315.32	1680	2020	600	700	560	420	340	670	500	400
[2]26	136.17 L	1/2	.500	359.49	1920	2310	700	800	640	480	380	780	580	460

[1] Values indicated are non-API.

[2] This is a non-API size.

CONSIDERATIONS IN SELECTION OF PIPE-PROTECTION MATERIAL

Twelve summary points of consideration in the selection of a material for underground pipe protection, viewed with respect to job requirements, are:

1. The material must adhere tenaciously to the pipe.
2. It should be non-absorbent and impervious to water, moisture vapor, etc.
3. It should possess good dielectric qualities.
4. It should be completely resistant to mineral acids, alkalies, salts, petroleum oils, and refined products such as gasoline and naphtha.
5. It should remain flexible at all temperatures.
6. Soil stress and pipe movement should not affect it.
7. Application should be simple, without unwieldy equipment, and preferably without heat and primer.
8. It should resist penetration by stones, wires, welding rod scraps, and other sharp materials found in the ditches and backfill.
9. It should be able to withstand rough handling without damage.
10. It should be quick setting and fast drying.
11. It should provide permanent protection to the pipe, yet not be prohibitive in cost.
12. The coating must be resistant and impervious to micro-organism attack.

WEIGHTS OF MECHANICAL JOINT PIPE FOR GAS

Standard thicknesses and weights of cast iron mechanical joint pipe centrifugally cast in metal and sand lined molds for gas

Note: Thicknesses in accordance with A.S.A. Specifications, 18,000 psi full length bursting tensile, 40,000 psi ring modulus of rupture. For pipe laid without blocks on flat bottom trench with tamped backfill under 5 feet of cover. For other conditions consult the manufacturer.

Size ins.	Thickness ins.	Outside Diam. ins.	Weight Based On 12 ft. Lgth.* Avg. per ft.	12 ft. Lgth.* per Lgth.	16 ft. Lgth.* Avg. per ft.	16 ft. Lgth.* per Lgth.	16½ ft. Lgth.* Avg. per ft.	16½ ft. Lgth.* per Lgth.	18 ft. Lgth.* Avg. per ft.	18 ft. Lgth.* per Lgth.	20 ft. Lgth.* Avg. per ft.	20 ft. Lgth.* per Lgth.
Class 10—10 Lb. Pressure												
4	.35(1)	4.80	16.6	200	16.4	260	16.3	270	16.2	290		
	or .38(2)	4.80	17.8	215	17.6	280	17.5	290	17.4	315		
6	.38(1)	6.90	26.1	315	25.7	410	25.6	420	25.5	460		
	or .41(2)	6.90	27.9	335	27.6	440	27.5	455	27.3	490		
8	.41	9.05	37.2	445	36.7	585	36.6	605	36.4	655		
10	.44	11.10	49.3	590	48.5	775	48.4	800	48.2	870		
12	.48	13.20	64.0	770	62.9	1005	62.8	1035	62.6	1125	62.3	1245
16	.50	17.40	90.7	1090	88.7	1420	88.6	1460	88.1	1585	87.6	1750
20	.57	21.60	128.7	1545	125.9	2015	125.7	2075	124.9	2250	124.2	2485
24	.63	25.80	170.2	2040	166.5	2665	166.1	2740	165.2	2975	164.2	3285
30	.73	32.00			241.5	3865	241.0	3975			238.0	4760
36	.81	38.30			322.4	5160						
42	.90	44.50			416.5	6665						
48	.98	50.80			519.0	8305						
Class 50—50 Lb. Pressure												
4	.35(1)	4.80	16.6	200	16.4	260	16.3	270	16.2	290		
	or .38(2)	4.80	17.8	215	17.6	280	17.5	290	17.4	315		
6	.38(1)	6.90	26.1	315	25.7	410	25.6	420	25.5	460		
	or .41(2)	6.90	27.9	335	27.6	440	27.5	455	27.3	490		
8	.41	9.05	37.2	445	36.7	585	36.6	605	36.4	655		
10	.44	11.10	49.3	590	48.5	775	48.4	800	48.2	870		
12	.48	13.20	64.0	770	62.9	1005	62.8	1035	62.6	1125	62.3	1245
16	.50	17.40	90.7	1090	88.7	1420	88.6	1460	88.1	1585	87.6	1750
20	.57	21.60	128.7	1545	125.9	2015	125.7	2075	124.9	2250	124.2	2485
24	.63	25.80	170.2	2040	166.5	2665	166.1	2740	165.2	2975	164.2	3285
30	.79	32.00			259.5	4150	259.0	4275			256.0	5120
36	.87	38.30			343.9	5500						
42	.97	44.50			445.7	7130						
48	1.06	50.80			557.1	8915						
Class 100—100 Lb. Pressure												
4	.35(1)	4.80	16.6	200	16.4	260	16.3	270	16.2	290		
	or .38(2)	4.80	17.8	215	17.6	280	17.5	290	17.4	315		
6	.38(1)	6.90	26.1	315	25.7	410	25.6	420	25.5	460		
	or .41(2)	6.90	27.9	335	27.6	440	27.5	455	27.3	490		
8	.41	9.05	37.2	445	36.7	585	36.6	605	36.4	655		
10	.44	11.10	49.3	590	48.5	775	48.4	800	48.2	870		
12	.48	13.20	64.0	770	62.9	1005	62.8	1035	62.6	1125	62.3	1245
16	.54	17.40	97.1	1165	95.0	1520	94.9	1565	94.5	1700	94.0	1880
20	.62	21.60	138.7	1665	135.9	2175	135.7	2240	134.9	2430	134.2	2685
24	.68	25.80	182.7	2185	178.5	2855	178.1	2940	177.2	3190	176.2	3525
Class 150—150 Lb. Pressure												
4	.35(1)	4.80	16.6	200	16.4	260	16.3	270	16.2	290		
	or .38(2)	4.80	17.8	215	17.6	280	17.5	290	17.4	315		
6	.38(1)	6.90	26.1	315	25.7	410	25.6	420	25.5	460		
	or .41(2)	6.90	27.9	335	27.6	440	27.5	455	27.3	490		
8	.41	9.05	37.2	445	36.7	585	36.6	605	36.4	655		
10	.44	11.10	49.3	590	48.5	775	48.4	800	48.2	870		
12	.48	13.20	64.0	770	62.9	1005	62.8	1035	62.6	1125	62.3	1245

* Including Bell. Calculated weight of pipe rounded off to nearest 5 pounds.
(1) Class 22 thickness.
(2) Class 23 thickness offers increased factor of safety and is recommended for use in areas of dense population and heavy traffic.
References: A.S.A.—A-21.7—pipe cast in metal molds. A.S.A.—A-21.9—pipe cast in sand lined molds. A.S.A.—A-21.11—mechanical joints.

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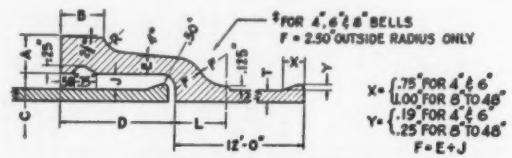
WEIGHTS OF MECHANICAL JOINT PIPE FOR GAS

Standard thicknesses and weights of cast iron mechanical joint pit cast pipe for gas

Note: Thicknesses in accordance with A.S.A. Specifications, 11,000 psi full length bursting tensile, 31,000 psi ring modulus of rupture. For pipe laid without blocks on flat bottom trench with tamped backfill under 5 feet of cover. For other conditions consult the manufacturer.

Size ins.	Outside Diam. ins.	Class 10 10 lb. Pressure Thickness ins.	Weight Based on 12 ft. Lgth.* Avg. per ft.	per Lgth.	Class 50 50 lb. Pressure Thickness ins.	Weight Based on 12 ft. Lgth.* Avg. per ft.	per Lgth.	Class 100 100 lb. Pressure Thickness ins.	Weight Based on 12 ft. Lgth.* Avg. per ft.	per Lgth.	Class 150 150 lb. Pressure Thickness ins.	Weight Based on 12 ft. Lgth.* Avg. per ft.	per Lgth.
4	4.80	.40	18.6	225	.40	18.6	225	.40	18.6	225	.40	18.6	225
6	6.90	.43	29.2	350	.43	29.2	350	.43	29.2	350	.43	29.2	350
8	9.05	.46	41.3	495	.46	41.3	495	.46	41.3	495	.46	41.3	495
10	11.10	.50	55.4	665	.50	55.4	665	.50	55.4	665	.50	55.4	665
12	13.20	.54	71.2	855	.54	71.2	855	.54	71.2	855	.54	71.2	855
16	17.40	.58	103.7	1245	.58	103.7	1245	.58	103.7	1245			
20	21.60	.66	147.2	1765	.66	147.2	1765	.71	157.1	1885			
24	25.80	.74	197.2	2365	.74	197.2	2365	.80	211.4	2535			
30	32.00	.87	291.8	3500	.87	291.8	3500						
36	38.30	.97	392.0	4705	.97	392.0	4705						
42	44.50	1.07	503.0	6035	1.07	503.0	6035						
48	50.80	1.18	634.3	7610	1.18	634.3	7610						

* Including Bell. Calculated weight of pipe rounded off to nearest 5 pounds.
References: Thicknesses—A.S.A.—A-21.3—pit cast for gas Mechanical joint—A.S.A.—A-21.11.



BELL NO. 1—STANDARD BELL

Nom. Diam. Ins.	Actual Outside Diam. Ins.	T	Actual Inside Diam. Ins.	Dimensions in Inches A	B	C	D	E	F	J	L	R	Approximate Weight in Pounds Bell †	Per ft. *	12' 0" Lgth.
4	4.80	.40	4.00	1.30	1.50	5.80	4.00	.59	1.09	.50	3.25	.75	27.0	19.50	234
6	6.90	.43	6.04	1.40	1.50	7.90	4.00	.62	1.12	.50	3.25	.80	39.5	30.58	367
8	9.05	.45	8.15	1.50	1.50	10.05	4.00	.69	1.19	.50	3.25	.80	52.8	42.42	509
10	11.10	.49	10.12	1.50	1.50	12.10	4.00	.69	1.19	.50	2.10	.90	57.93	55.91	671
12	13.20	.54	12.12	1.60	1.50	14.20	4.50	.75	1.25	.50	2.20	1.00	79.47	73.83	886
16	17.40	.62	16.16	1.80	1.75	18.40	4.50	.90	1.40	.50	2.50	1.10	125.18	112.58	1351
20	21.60	.68	20.24	2.00	1.75	22.85	4.50	.97	1.60	.63	2.80	1.15	169.10	153.83	1846
24	25.80	.76	24.28	2.10	2.00	27.05	5.00	1.05	1.68	.63	2.80	1.25	235.10	206.41	2477
30	31.74	.85	30.04	2.30	2.00	32.99	5.00	1.15	1.78	.63	3.00	1.30	315.20	284.00	3408
36	37.96	.95	36.06	2.50	2.00	39.21	5.00	1.25	1.88	.63	3.20	1.40	410.20	379.25	4551
42	44.20	1.07	42.06	2.80	2.00	45.45	5.00	1.40	2.03	.63	3.40	1.45	537.50	497.66	5972
48	50.50	1.26	47.98	3.00	2.00	51.75	5.00	1.50	2.13	.63	3.60	1.60	657.00	663.50	7962

Note—Pipe heavier than these standards may be made by reducing the cores, or internal diameters "C" and "D"; same for specials.

Dimension "L" for sizes 4", 6" and 8", and Dimension "F", shown in sketch as 2.50 (outside radius only), apply to bells of *straight pipe only*. For bells of *special castings* the correct dimensions for "F" and "L" are.

Size	"F"	"L"
4	1.99	1.90
6	1.12	2.00
8	1.19	2.10

*Weight per foot includes Bell and Bead.
†Weight of Bell includes only metal beyond O. D. of pipe.
‡See Sketch for Special outside radius dimensions for 4", 6" and 8" Bells.

"CARBOSEAL" ANTI-LEAK

"Carboseal"* anti-leak is a product made by Carbide and Carbon Chemicals Corp. and widely sold for correcting leakage in bell and spigot joints in cast iron systems distributing dry gas.

Gases inherently dry are:

(a) Natural gas.

(b) Hydrocarbon gases such as propane and butane with or without air carburetion.

(c) Manufactured gas passed through transmission lines at high or intermediate pressure and distributed at low pressure through district governors in the same system.

(d) Manufactured gas which has been compressed for transmission at high pressures to neighboring communities for low pressure distribution.

(e) Mixed manufactured and natural gas.

The problem presented by increased joint leakage attendant upon the substitution of dry gas for wet was recognized many years ago and various means were adopted for correcting this condition:

(a) A method reported to be entirely satisfactory by many companies consists of applying a leak clamp at each joint after properly preparing the face of the bell to receive the clamp. This involves expensive excavation and repaving costs in addition to the cost of the clamp itself.

(b) Rehydration. Dry gases stored in water-sealed holders pick up some water and the send-out may be partially saturated particularly in the summer months. Any benefit secured from this water vapor is probably restricted to mains within a limited radius.

(c) Oil fogging. Oil fogging has been adopted alone or in conjunction with rehydration in many systems. The principal claims for oil fogging are that it postpones drying out of the packing in bell and spigot joints following a changeover, prevents the formation of, and lays, dust in the system and postpones drying out of leather meter diaphragms where the original dressing oils have been leached out by condensable hydrocarbons present in "wet" gas formerly distributed.

"Carboseal" weighs approximately 9.2 lb. per gal. The liquid has solvent properties for tar and gum and penetrates the packing material readily, swelling it approximately 45 per cent by volume. It will climb to a vertical height of 24 in. in a joint.

The liquid has a high boiling point and a very low vapor pressure. Tendency to evaporate is negligible because of these properties and because the liquid is absorbed intimately into the jute fibres where the swelling action is produced. This material has been variously estimated by users to have a permanency of at least ten to twelve years. The components of the material are inherently non-corrosive. Inhibitors have been added to provide corrosion protection.

The most widely used method of applying the antileak is to insert it at the high points in the system, recovering for re-use the excess material which flows by gravity into the drips. Filling stations at the high points can be established by drilling and tapping the main. Theoretically, the amount required to treat a mile of 3-in. main or its equivalent is 265 lb. This quantity will saturate the packing, fill all the voids, and coat the entire inner surface of pipe which is free from dust and rust deposits. Actual experience over a period of years indicates that due to the presence of such factors as sags and dust in the main, the average total quantity required is 450 lb. per mile of 3-in. main or equivalent. The total cost of treatment including the liquid required, labor and materials, runs from $82 to $600 per mile of 3-in. equivalent with the weighted average in the neighborhood of $300 per mile.

On a project where it is proposed to treat a very old bell and spigot joint cast iron main, one should first excavate and then secure some yarn from old joining material. This yarn should be tested for its capillary attraction qualifications. If found to have lost most of its capillary attraction and does not absorb and carry the "carbosealing" liquid material, the gas joint leaks may not be stopped when the main is treated with Carboseal. On the other hand, should the capillary attraction be good, the leaky gas main joints will probably be stopped upon treatment with this material.

* The word "Carboseal" is a registered trade-mark of Carbide and Carbon Chemicals Corporation.

RESISTANCE OF PIPE FITTINGS TO FLOW EQUIVALENT FEET OF STRAIGHT PIPE

Steam—Air—Gas

Nominal pipe size inches	Actual inside diameter inches	Gate Valve	Long radius ell or on run of standard tee	Medium radius ell or on run of tee reduced in size 25 per cent.	Standard ell or on run of tee reduced in size 50 per cent.	Angle Valve	Close return bend	Tee through side outlet	Globe Valve
Resistance factor for type of fitting		0.25	0.33	0.42	0.67	0.90	1.00	1.33	2.00
½	0.622	0.31	0.41	0.52	0.84	1.1	1.3	1.7	2.5
¾	0.824	0.44	0.57	0.73	1.2	1.6	1.8	2.3	3.5
1	1.049	0.57	0.77	0.98	1.6	2.1	2.3	3.1	4.7
1¼	1.380	0.83	1.1	1.4	2.3	2.9	3.3	4.4	6.5
1½	1.610	0.98	1.3	1.6	2.6	3.5	3.9	5.2	7.8
2	2.067	1.3	1.7	2.2	3.6	4.8	5.3	7.1	10.6
2½	2.469	1.6	2.2	2.8	4.4	5.9	6.6	8.7	13.1
3	3.068	2.1	2.8	3.6	5.7	7.7	8.5	11.4	17.1
4	4.026	3.0	3.9	5.0	7.9	10.7	11.8	15.9	23.7
5	5.047	3.9	5.1	6.5	10.4	13.9	15.5	20.7	31.0
6	6.065	4.8	6.4	8.1	12.9	17.4	19.3	25.6	38.5
8	7.981	6.7	8.9	11.3	17.9	24.1	26.8	35.6	53.5
10	10.020	8.8	11.5	14.7	23.4	31.5	35.0	46.6	70.0
12	12.000	10.9	14.4	18.4	29.3	39.3	43.7	58.1	87.4

Based on Foster's formula $L = 43.7\ r.\ d.^{1.9}$

in which L = equivalent length straight pipe in feet

r = resistance factor

d = diameter of fitting in feet

(A. S. M. E. Trans.)

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WELDING—PIPE LINES (OIL AND GAS)

The simplicity, speed and high quality of arc welding has resulted in almost all cross-country pipe lines being completely welded.

Following is a general description of modern practice in the construction of oil and gas lines, using the plain end joint with liner for gas lines, and the plain end joint without liner for oil lines.

Where so called "roll welding" of pipe sections can be done, out in front of the entire construction gang goes the lineup and tacking crew. Aided by a tractor and hoist, they put the pipe lengths on ball-bearing dollies for rolling. The tack welder tacks the adjacent lengths of pipe together usually at four points in the circumference. He joins as many lengths as the nature of the line and the contour of the country will permit. The long tack-welded section is then left on the dollies ready for the firing line welders who follow close behind.

In recent years, the "stove-pipe" method has come into widest use, especially for lines over rough terrain where roll-welding of long sections is difficult. It is also used over fairly smooth or rolling country. Here, all joints (usually plain end without liner) are position-welded like bell-hole joints. One joint at a time is added to the line, making it possible to reduce the size of the crew and amount of equipment, and keep operations bunched together under one supervisor. During alignment and tacking, the joint is usually held in place by a line-up clamp or "grasshopper." After tacking, two bell-hole welders work simultaneously on both sides of the joint, making the complete first bead, each welder coming down from the top.

The wall thickness of the pipe for river crossings is generally 50% to 100% greater than that used in the rest of the line. The pipe is roll-welded and bell-hole welded into a section long enough to cross the river. Each joint is often reinforced by a welded-on sleeve. Special river clamps, four to ten feet long and weighing 1000 to 3000 lbs. each are often bolted to the pipe at intervals, serving as a means of anchoring. The pipe section is then attached by cable to tractors and pulled onto pontoons from which it is guided by stakes into a dredged out ditch in the river bottom. It is usually buried at a minimum depth of eight feet.

The welding speed data in the accompanying tables are based on the average time consumed in making all welds on an average length pipe line from start to finish of the job, including delays, outages and moving time. In other words, it is the average production that can be expected per joint per hour on pipe line construction except where otherwise noted.

AVERAGE SPEEDS FOR PIPE LINE WELDING

	Roll Welding Without Back-Up Ring	*Position Welding Without Back-Up Ring*
Size	*Average Welds Per Hour*	*(After 1st Bead Run By Tackers) Average Welds Per Hour*
6″	6.0	6.5
8″	5.5	5.0
10″	4.0	4.5
12″	3.5	3.75
14″	3.0	3.0
16″	2.75	2.50
18″	2.50	2.25
20″	2.25	2.25
22″	2.1	2.0
24″	2.0	2.0
26″	1.5	1.25
30″	1.25	1.0

Note: Roll and Position Welding Without Back-up Ring: For all sizes of pipe use a space of 1/16″ to 1/8″.

POUNDS OF ELECTRODE PER WELD*

Size Pipe	*Pounds*
6″	.75
8″	1.00
10″	1.25
12″	1.50
14″	1.75
16″	2.00
18″	2.25
20″	2.50
22″	2.75
24″	3.00
26″	3.25
30″	4.00

* Based on 1/4″ to 5/16″ wall thickness pipe.

RECOMMENDED SIZES OF ELECTRODE FOR PIPE LINE WELDING

	Roll Welding Without Back-Up Ring			*Position Welding Without Back-Up Ring "Stove Pipe" or "Tie In" Method*		
Size	*Stringer Bead*	*Second Bead*	*Third Bead*	*Stringer Bead*	*Second Bead*	*Third Bead*
4″	5/32″	3/16″	1/4″	....	....	....
6″	5/32″	1/4 ″	1/4″	5/32″	5/32″	3/16″
8″	5/32″ or 3/16″	1/4 ″	1/4″ or 5/16″	5/32″	5/32″	3/16″
10″	5/32″ or 3/16″	1/4 ″	1/4″ or 5/16″	5/32″	5/32″	3/16″
12″	5/32″ or 3/16″	1/4 ″	1/4″ or 5/16″	5/32″	5/32″	3/16″
14″	5/32″ or 3/16″	1/4 ″	1/4″ or 5/16″	5/32″	5/32″	3/16″
16″	5/32″ or 3/16″	1/4 ″	1/4″ or 5/16″	5/32″	5/32″	3/16″
18″	5/32″ or 3/16″	1/4 ″	1/4″ or 5/16″	5/32″	5/32″	3/16″
20″	5/32″ or 3/16″	1/4 ″	1/4″ or 5/16″	5/32″	5/32″	3/16″
22″	5/32″ or 3/16″	1/4 ″	1/4″ or 5/16″	5/32″	5/32″	3/16″
24″	5/32″ or 3/16″	1/4 ″	1/4″ or 5/16″	5/32″	5/32″	3/16″
26″	5/32″ or 3/16″	1/4 ″	1/4″ or 5/16″	5/32″	5/32″	3/16″
30″	5/32″ or 3/16″	1/4 ″	1/4″ or 5/16″	5/32″	5/32″	3/16″

Position welding with back-up ring: Use 3/16″ rod for all beads on all sizes of pipe.

Note: Use 3/16″ electrode on additional beads when necessary.

The firing line crew, including several welders, completes the welds of the long sections. These operators weld at the top of the pipe while a helper turns the pipe by means of a chain pipe wrench. Thus, all welding is done in a flat, downhand position, and by using large-size electrodes (1/4″, 5/16″ and sometimes 3/8″) and heavy welding current, high welding speeds are obtained. After completion of each bead, a helper cleans all of the slag from the weld. Each completed weld is inspected for any imperfections before the welder proceeds to the next joint. When the section is entirely welded, the pipe is rolled off the dollies and the pipe sections are painted and then joined into a continuous stretch by "bell-hole" welding.

This pipe is placed on timber skids near or over the trench and, in this position, it is "bell-hole" welded. Here, instead of having the pipe rolled beneath the arc, the operator plies the arc around the pipe. For these welds, he uses smaller sized electrodes (5/32″ or 3/16″) with 125 to 200 amperes.

REQUIRED WATER HEATER CAPACITIES

Capacity of Hot Water Equipment Needed to Supply Fixtures in Various Types of Buildings
Gallons Per Maximum Hour

Fixture	Apt. House	Club	Gymnasium	Hospital	Hotel	Indst. Plant	Laundry	Office Bldg.	Public Bath	Private House	School	Y.W.C.A. Y.M.C.A.
Wash Basin (Private)	3	3	3	3	3	3	3	3	3	3	3	3
Wash Basin (Public)	5	8	10	10	10	15	10	15	15	..	15	15
Bath Tub	15	15	30	15	15	30	..	..	45	15	..	30
Dish Washer	15	30	..	30	30	30	..	..	.	15	15	..
Foot Basin	3	3	..	3	3	..	..	..	..	3	..	10
Kitchen Sink	10	20	..	20	20	20	..	..	..	10	10	20
Laundry Tub (Stationary)	25	35	..	35	35	..	45	..	45	25	..	45
Laundry Tub (Revolving)	75	75	..	100	150	..	100	..	100	75	..	100
Pantry Sink	10	20	..	20	20	..	10	..	..	10	20	20
Shower	100	200	300	100	100	300	..	..	300	100	300	200
Slop Sink	20	20	..	20	30	20	..	20	20	15	20	20
Dish Washer				250 Gallons per hour for each 500 people								
% of Total Water likely be drawn in one hour	20	30	60	40	30	70	80	15	80	30	25	30

Buenger, A. *Journ A.S.H. & V.E.*,

APPROXIMATE FUEL CONSUMPTIONS FOR WATER HEATING

Fuel	B.t.u. in Unit as Sold	Typical Overall Efficiency	Fuel Consumption per Month (Based on a Daily Draw of 50 Gallons, or 1500 Gallons of Hot Water Monthly)
Gas:			
Manufactured	530 B.t.u. per cubic foot	68–61%	2690–2940 cubic feet
Natural	1100 B.t.u. per cubic foot	68–61%	1350–1475 cubic feet
Mixed	Varies with mixture	68–61%	Consult local company
Electricity	3412 B.t.u. per K.w.h.	86-74%	340–390 K.w.h.
Oil:			
Summer	138,000 B.t.u. per gallon	20– 8%	36–87 gallons
Winter	138,000 B.t.u. per gallon	45–20%	16–34 gallons
Kerosene	136,000 B.t.u. per gallon	40–25%	18–28 gallons
Coal:			
Indirect Heater	12,000 B.t.u. per pound	27–24%	305–350 pounds
Furnace Coil	12,000 B.t.u. per pound	28–24%	302–348 pounds
Pot Stove	12,000 B.t.u. per pound	17–13%	504–656 pounds

CAPACITY OF PIPE

Cubic feet of gas per hour 0.3" pressure drop; 0.6 spec. gr.

Length of Pipe (Ft.)	Diameter of Pipe Inches ½	¾	1	1¼	1½	2	3	4
15	76	172	345	750	1,220	2,480	6,500	13,880
30	52	120	241	535	850	1,780	4,700	9,700
45	43	99	199	435	700	1,475	3,900	7,900
60	38	86	173	380	610	1,290	3,450	6,800
75		77	155	345	545	1,120	3,000	6,000
90		70	141	310	490	1,000	2,700	5,500
105		65	131	285	450	920	2,450	5,100
120			120	270	420	860	2,300	4,800
150			109	242	380	780	2,090	4,350
180			100	225	350	720	1,950	4,000
210			92	205	320	660	1,780	3,700
240				190	300	620	1,680	3,490
270				178	285	580	1,580	3,250
300				170	270	545	1,490	3,000

MULTIPLIERS

To convert gas flow at 0.6 spec. grav. to flow at another gravity

Specific Gravity	Multiplier
2.0	0.547
1.5	0.633
1.4	0.654
1.3	0.680
1.2	0.707
1.1	0.740
1.0	0.775
0.9	0.817
0.8	0.866
0.7	0.926
0.6	1.000
0.5	1.095
0.4	1.225

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RAPID SURVEY METHOD OF GAS REQUIREMENTS AND COSTS

In many of its phases, the selling of gas heat is very much like other specialty selling where the cost of the item or of the service to be furnished depends on the particular conditions surrounding the individual prospect.

The estimate of annual operating cost for one prospect may figure only $50.00, whereas that for another would be $500.00. When the one in the $500.00 class first makes inquiry about gas heat, his interest may be based on thinking in terms of $50.00. Likewise, the one who is in the $50.00 class may not have exhibited any interest, because he was thinking in terms of $500.00.

A method, therefore, whereby the salesman in the field can figure the estimate with reasonable accuracy and in just a few minutes time, is of great assistance in qualifying prospects. Such a method can be made sufficiently accurate to justify the salesman in attempting to close the order on the basis of the rapid survey method. If successful, then before the installation is made, his engineering department, if it so desires, can make a more elaborate survey and estimate. This can be done as if it is merely a part of the usual installation routine, so that the customer's confidence in the salesman is not affected in any way. Should this detailed survey show any glaring discrepancies, the matter can be taken up with the customer in advance of installation, so that no one will be unfavorably affected.

To show how such a rapid survey can be developed, the starting point is the formula used by heating engineers in figuring the seasonal operating cost to take care of any given area of wall, ceiling, or floor.

FORMULA

(Heat loss in Btu per Hour)

$$\frac{\text{Area} \times \text{Heat Transfer Coefficient} \times \text{Temp. Rise} \times \text{Hrs. Heated} \times \text{Degree Days} \times \text{Gas Rate in Cts. Per M Cu. Ft.}}{\text{Temperature Rise} \times \text{Btu Heat Content} \times \text{Efficiency} \times 1000 \times 100} = \text{Season's Operating Cost in Dollars for that Area}$$

While there are many factors in the long formula, examination will show that for any certain type of construction practically all of them are constant for any given territory. The coefficient of any certain material is always the same—the temperature rise is nearly always figured at 70 degrees—the temperature differential between basement and house interior 20 degrees—and between interior and attic 35 degrees—the number of hours per day is always 24—the number of degree days for any given territory is regarded as a constant—the gas rate and the Btu content are constant for a territory. While the efficiency factor may vary slightly with different types of equipment, an average efficiency of 75 per cent can be used for reasonably accurate results. This means that all of the factors in that long formula can be condensed for any territory into one single factor for each type of construction. Then it is simply a case of multiplying the given area by one factor instead of working out the entire formula shown above.

Another point of simplification is to measure the house as a whole rather than to measure the individual rooms. It is simple for the salesman to compute the volume by measuring the width, height, and depth of the house. Naturally, if the prospect states that certain rooms have not been heating satisfactorily with the old furnace equipment, then individual rooms should be measured and duct work or radiation checked. Just as in the case of figuring the heat loss through the walls, ceiling, or floor, this volume can be multiplied by a single constant to determine the seasonal operating cost for offsetting loss by infiltration.

With the above thought in mind, a single factor, which for purposes of clarity in explaining is called factor "F," has been worked out for the most commonly encountered types of construction. To convert this factor "F" into the correct constant for any territory, it is only necessary to multiply it by a certain multiplier, designated as "M," with "M" being determined as follows:

$$M = \frac{\text{Local Degree Days} \times \text{Average Local Heating Rate in Cents per M/Cu. Ft.}}{\text{Btu Content of Local Gas}}$$

or

$$M = \frac{\text{Local Degree Days} \times \text{Rate per Therm in Cents}}{100{,}000}$$

The following table gives the factor "F" for the most usual types of building constructions. Figure local multiplier, "M," as outlined above, multiply M by F and then it is possible to fill in this table with the local constant which will be used in figuring the seasonal operating cost to offset the heat loss through any given area of wall, ceiling, or floor.

Type of Material	*Factor "F"*	*Multiplier "M"*	*Final Constant*
Single Glass	0.000352	.....	.....
Double Glass	0.000143	.....	.....
Walls:			
8″ Brick, Sheathing, Stud, L&P	0.000085	.....	.....
Stucco, Wood & Plaster	0.000099	.....	.....
Stone, Tile, Furred, L&P	0.000077	.....	.....
Clapboards, Studding, L&P	0.000080	.....	.....
Floors:			
Wood Floor. No Ceiling Below	0.000042	.....	.....
Double Floor. L&P Below	0.000022	.....	.....
Ceilings:			
Plaster Board & Plaster	0.000098	.....	.....
Rigid Insulation & Plaster	0.000056	.....	.....
Roofs:			
Tile or Slate on Wood	0.000179	.....	.....
Shingles, Sheathing, Stud, L&P	0.000102	.....	.....
Volume:			
To offset air infiltration:			
One air change per hour	0.0000058	.....	.....
One and one-half air changes	0.0000087	.....	.....
Two air changes per hour	0.0000116	.....	.....

Note: For any wall construction not listed above which may be found to be common in the locality, the factor "F" may be obtained by:

Coefficient of Transmission $\times$ 0.00032 = F

After the above final constants for the territory have been worked out, it is recommended that they be printed on a survey card arranged along the lines of the one reproduced here. The reverse side of the card can carry the usual general information as to the prospect's name and address, date of survey, and the like.

With permission, from Surface Combustion Corp.

Suggested Form For Rapid Survey Method

Area Sq. Ft.	*Material*	*Local Factor*	*Operating Cost Per Season*
.....	Glass: Single	.....	$.....
.....	Glass: Double	.....	.....
.....	Walls (Net): 8" Brick	.....	.....
.....	Stucco, Tile & Plaster	.....	.....
.....	Stone, Tile, Furred, L&P	.....	.....
.....	Clapboards, Studding, L&P	.....	.....
.....	.....	.....	.....
.....	Floors: Wood floor, no ceil. below ...	.....	.....
.....	Double floor: L&P below joists ...	.....	.....
.....	.....	.....	.....
.....	Roofs: Tile or slate on wood	.....	.....
.....	Shingles, Sheathing, Studding, L&P	.....	.....
.....	.....	.....	.....
Cu. Ft.	*Volume*		
.....	Infiltration: 1 air change per hr	.....	.....
.....	1½ air changes per hr	.....	.....
.....	2 air changes per hr	.....	.....
	Total Operating Cost Per Season	.....	$.....

If Btu. heat loss per hour is desired, use formula $= \frac{218{,}750 \times \text{Season's Cost}}{M}$

HEAT DELIVERY OF SPACE HEATING EQUIPMENT

STEAM: 1 sq. ft. cast iron radiation = 240 Btu/hr. (2 Lb. steam 70° F. room temp.)

HOT WATER: 1 sq. ft. cast iron radiation = 150 Btu/hr. 70° F. Room Temp.

FORCED HOT WATER: 1 sq. ft. cast iron radiation = 200 Btu/hr. (70° F. Room Temp.)

GRAVITY WARM AIR: 1 sq. in. of basement duct (175° F. register temperature)

= 110 Btu/hr. on first floor
= 166 Btu/hr. on second floor
= 200 Btu/hr. on third floor

FORCED WARM AIR: *The following formula gives the heat delivered at the register of a forced warm air heating system.*

$$H = A \times V \times 60 \times W \times S \times (t_d - t_r)$$

Symbols:

H = Heat delivered in Btu per hour.
A = Net area of discharge register in sq. ft.
V = Velocity of air leaving register in ft. per minute.
W = Weight of air at temperature t_d in pounds per cubic foot.
S = Specific heat of air in Btu per pound per degree F. at temperature t_d.
t_d = Temperature in degrees F. of air leaving register.
t_r = Temperature in degrees F. of space being heated.

With permission, "Surface Combustion Industrial Heating Handbook."

Example

CONDITIONS

Assume the following conditions for the computation of the seasonal operating cost in a home:

Two and one-half story residence
Walls: 8" brick, lath and plaster inside over sheathing
Ceilings second floor: Plaster board and plaster
No flooring in attic
Floors: Frame construction, single thickness
Single glass windows
Air changes per hour: 1
Gross wall area:
  First floor, 1300 sq. ft.
  Second floor, 1150 sq. ft.
Glass area:
  Windows and doors
  First floor, 190 sq. ft.
  Second floor, 130 sq. ft.
Area second floor ceiling: 1010 sq. ft.
Area first floor: 1010 sq. ft.
Cubical contents:
  First floor, 9100 cu. ft.
  Second floor, 8700 cu. ft.
  Degree days 6000
  Gas rate 40c/M cu. ft.
  Btu content 530

PRELIMINARY

$$M = \frac{6000 \times 40}{530} = 453$$

Final constant for glass area	=	.000352 × 453	= .159
Final constant for wall area	=	.000085 × 453	= .0385
Final constant for floor area	=	.000042 × 453	= .019
Final constant for ceiling area	=	.000098 × 453	= .044
Final constant for infiltration	=	.0000058 × 453	= .0026

SOLUTION

320 square feet glass area	×	.159	=	$ 50.88
2,130 square feet wall area	×	.0385	=	82.00
1,010 square feet floor area	×	.019	=	19.19
1,010 square feet ceiling area	×	.044	=	44.44
17,800 cubic feet infiltration	×	.0026	=	46.28
				$242.79

COMPARISON OF GAS AND ELECTRICITY IN COMMERCIAL COOKING

THE opportunity was provided for making a study by the replacement of the commercial cooking equipment in Alfonso's Restaurant in Washington, D. C., where a careful record was kept of operating conditions, meals served and utility consumptions. As a result, replacement factors for gas and electricity in a typical commercial cooking establishment were obtained, that were based on long periods of practical operation under identical conditions.

Results of study

NEW GAS EQUIPMENT VERSUS NEW ELECTRIC EQUIPMENT

Electricity used for cooking during the months, October, 1946 – through July, 1947: 116,190 kwh.

Gas used for cooking during the ten months from October, 1947, through July, 1948, totaled 5,434 therms.

Electric cooking equipment having a rating of 82.8 kw added 45.15 kw to the maximum demand, which amounted to 54% of the connected load.

When electricity was used for cooking, average monthly consumption:

Cooking only	11,619 kwh
Lights and other uses	3,601 kwh
Total for all purposes	15,220 kwh

Maximum electric billing demand (Connected cooking load of kitchen 82.8 kw)

Cooking only	45.15 kw
Lights and other uses	14.75 kw
Total demand	59.90 kw

When gas was used for cooking:

Average monthly consumption of gas for cooking ..... 543 therms

Average monthly consumption of electricity for lights and other uses 3601 kwh

Maximum electric billing demand for lights and other uses ..... 14.75 kw

The data obtained in this study furnish authentic replacement factors indicating the relative consumptions of gas and electricity for commercial kitchen operation, typified by Alfonso's Restaurant:

HEATING VALUE OF GAS BTU	1000 CU. FT. ARE EQUIVALENT TO THIS MANY KWH	1 KWH IS EQUIVALENT TO THIS MANY CUBIC FEET
525	112.1	8.90
540	115.2	8.65
850	181.9	5.50
1,000	213.7	4.68
1,100	235.1	4.25
2,500	534.0	1.87

1.371 Btu of gas are equivalent to 1 Btu of electricity

.0468 therms of gas are equivalent to 1 kwh of electricity

1 therm of gas is equivalent to 21.4 kwh of electricity

These factors are based upon actual amounts of gas and electricity used for cooking purposes without correction for the difference in the number of meals served, although this results in a slight benefit to electricity. Actually, 1% more meals were cooked with gas.

"A Comparison of Gas and Electric Usage for Commercial Cooking," American Gas Association.

RELATIVE COST OF GAS AND ELECTRIC COOKING

The conclusions reached by the American Gas Association in their Bulletin No. 6 are as follows:

Item	Scope of Test	Energy Ratio
1.	Top burner performance	1.532
2.	Oven performance	2.624
3.	Week's menu (upper income)	2.077
4.	Week's menu (limited income)	1.799
5.	Food for Infant	1.754

Accepting an energy ratio of 1.9 the following formula will facilitate calculators:

$$\frac{1.9 \times 3413}{\text{B.t.u. of Gas}} = \text{cu. ft. of gas equivalent to 1 Kwh.}$$

in which if 525 Btu. per cu. ft. of gas is being burned, then by substitution

$$\frac{1.9 \times 3413}{525} = 12.35 \text{ cu. ft. of gas equivalent to 1 Kwh.}$$

With the foregoing as a basis, the tabulation below represents the "break even" gas cost per Mcf. for electricity at different costs per Kwh., fuel cost only being considered on a 1.9 energy ratio.

Cost per Kwh., Cents	Break-even Cost per Mcf. B.t.u. of Gas per Cu. Ft.					
	500	525	550	750	1000	1100
1.0	$0.77	$0.81	$0.85	$1.16	$1.54	$1.70
1.5	1.16	1.21	1.37	1.73	2.31	2.54
2.0	1.54	1.62	1.70	2.32	3.08	3.40
2.5	1.93	2.02	2.12	2.89	3.86	4.24
3.0	2.32	2.42	2.54	3.46	4.62	5.08
3.5	2.70	2.83	2.97	4.05	5.40	5.94
4.0	3.08	3.24	3.40	4.64	6.16	6.80
5.0	3.86	4.04	4.24	5.78	7.72	8.48

COMMERCIAL COOKING AND BAKING FUEL REQUIREMENTS

In Btu per meal served

Class	Electricity	Gas	Oil	Coal
Clubs, First Class	4,270	8,280	11,450	15,750
Hotels, First Class	3,415	6,620	9,200	12,650
Cafeteria, First Class	2,140	4,080	5,670	7,800
Institutions	1,708	3,340	4,630	6,360
Hospitals	1,280	2,490	3,450	4,750
College Mess Halls	482	935	1,300	1,785

Steam tables, coffee urns, hot water, dish washing, etc. adds 30 to 50% to the above figures.

With permission, "Surface Combustion Industrial Heating Handbook."

INDUSTRIAL HEATING OPERATIONS

Materials, operations and approximate temperature range

MATERIAL	Operation	Approx. Temp. Range (°F)
Aluminum Alloy	Aging	250-460
Aluminum Alloy	Annealing	450-775
Aluminum Alloy	Forging	750-900
Aluminum Alloy	Heat Treating	310-1000
Aluminum	Melting	1200-1400
Aluminum Alloy	Die Casting	1250-1400
Antimony	Melting Point	1166
Asphalt	Melting	350-450
Babbitt	Melting	600-800
Brass	Annealing	600-900
Brass	Extruding	1400-1450
Brass	Forging	1200-1400
Brass, Yellow	Melting	1705
Brass, Red	Melting	1830
Bread	Baking	300-500
Brick	Burning	1800-2600
Brick, Refractory	Burning	2500-3000
Bronze, 5% Alum.	Melting	1940
Bronze, Man.	Melting	1645
Bronze, Phos.	Melting	1920
Bronze, Tobin	Melting	1625
Cadmium	Melting Point	610
Cake (Food)	Baking	300-350
Calcium	Melting Point	1562
Calender Rolls	Heating	300
Candy	Cooking	225-300
Cast Iron	Annealing	1600-1700
Cast Iron	Malleablizing	1650-1800
Cast Iron	Vitreous Enameling	1200-1300
Cement	Kiln Firing	2800-3000
China	Glazing	1500-1900
Clay, Refrac.	Burning	2200-2600
Cobalt	Melting Point	2714
Coffee	Roasting	600-800
Coke	By-Product Oven	1830-2730
Cookies	Baking	375-450
Copper	Annealing	800-1200
Copper	Refining	2100-2600
Copper	Melting	2100-2300
Copper	Smelting	2100-2600
Cores, Sand	Baking	250-550
Cupronickel, 15%	Melting	2150
Cupronickel, 30%	Melting	2240
Electrotype	Melting	740
Enamel	Baking	250-450
Everdur 1010	Melting	1865
Frit	Smelting	2000-2400
Glass	Annealing	800-1200
Glass	Melting, Pot Furnace	2300-2500
Glass, Bottle	Melting, Tank Furnace	2500-2900
Glass, Flat	Melting, Tank Furnace	2500-3000
Gold	Melting	1950-2150
Iron	Blast Furnace Tap.	2500-2800
Iron, Malleable	Melting	2400-3100
Iron, Malleable	Annealing	1500-1700
Japan	Baking	300-450
Lacquer	Drying	150-200
Lead	Melting	620-750
Lead	Blast Furnace	1650-2200
Lead	Refining	1800-2000
Magnesium	Aging	350-400
Magnesium	Heat Treating	730-760
Magnesium	Melting	1250-1300
Magnesium	Superheating	1450-1650
Meat	Smoking	100-150
Mercury	Melting Point	-38
Molds, Foundry	Drying	400-750
Molybdenum	Melting Point	4757
Monel Metal	Annealing	1100-1480
Monel Metal	Melting	2800
Muntz Metal	Melting	1660
Nickel	Annealing	1100-1480
Nickel	Melting	2650
Palladium	Melting Point	2829
Phosphorous, Yellow	Melting Point	111
Pie	Baking	500
Pigment	Calcining	1600

(Continued on next page)

INDUSTRIAL HEATING OPERATIONS

Materials, operations and approximate temperature range

(Continued)

MATERIAL	Operation	Approx. Temp. Range (°F)
Platinum	Melting	3224
Porcelain	Burning	2600
Potassium	Melting Point	145
Potato Chips	Frying	350-400
Primer	Baking	300-400
Silicon	Melting Point	2606
Silver	Melting	1750-1900
Sodium	Melting Point	208
Solder	Melting	400-600
STEEL		
Steel, Sheet	Blue Annealing	1400-1600
Sheet	Box Annealing	1500-1700
Sheet	Bright Annealing	1250-1350
Sheet	Job Mill Heating	2000-2100
Sheet	Mill Heating	1800-2100
Sheet	Open Annealing	1500-1700
Sheet	Tin Plating	650
Sheet	Vitreous Enameling	1400-1650
Sheet, Tin Plate	Box Annealing	1200-1650
Sheet, Tin Plate	Hot Mill Heating	1800-2000
Sheet, Tin Plate	Lithographing	300
Steel	Bessemer Converter	2800-3000
Steel	Calorizing	1700
Steel	Carburizing	1500-1700
Steel	Case Hardening	1600-1700
Steel	Cyaniding	1400-1800
Steel	Drawing Forgings	850
Steel	Drop Forging	2200-2400
Steel	Forging	1700-2150
Steel	Form-Bending	1600-1800
Steel	Galvanizing	800-900
Steel	Heat Treating	700-1800
Steel	Lead Hardening	1400-1800
Steel	Melting, Open Hearth	2800-3100
Steel	Melting, Electric Furn.	2400-3200
Steel	Normalizing	1650-1900
Steel	Rolling	2300
Steel	Soaking Pits	1900-2100
Steel	Upsetting	2000-2300
Steel	Welding	2400-2800
Steel Bars	Heating	1900-2200
Steel Billets	Heating	2250
Steel Blooms	Heating	2250
Steel Bolts	Heading	2200-2300
Steel Castings	Annealing	1300-1600
Steel Flanging	Heating	1800-2100
Steel Ingots	Heating	2000-2200
Steel Nails	Blueing	650
Steel Pipe	Butt Welding	2400-2600
Steel Rails	Hot Bloom Reheating	1900-2050
Steel Rivets	Heating	2000-2200
Steel Rod	Mill Heating	1900-2100
Steel Shape	Heating	1900-2200
Steel Slabs	Heating	2000-2200
Steel Spikes	Heating	2000-2200
Steel Springs	Annealing	1500-1650
Steel Wire	Annealing	1200-1400
Steel Wire	Pot Annealing	1650
Steel Wire	Baking	300-350
Steel, Alloy Tool	Hardening	1425-2150
Steel, Alloy Tool	Preheating	1200-1500
Steel, Alloy Tool	Tempering	325-1250
Steel, Carbon	Hardening	1360-1550
Steel, Carbon Tool	Hardening	1450-1500
Steel, Carbon	Tempering	300-1100
Steel, Carbon Tool	Tempering	300-550
Steel, Hi-Carbon	Annealing	1400-1500
Steel, Hi-Speed	Hardening	2250-2375
Steel, Hi-Speed	Preheating	1450-1600
Steel, Hi-Speed	Tempering	1000-1150
Steel, S.A.E.	Annealing	1400-1650
Tin	Melting	500-650
Type Metal	Stereotyping	525-650
Type Metal	Linotyping	550-650
Type Metal	Electrotyping	650-750
Varnish	Cooking	520-600
Vitreous Enamel	Firing	1400-1700
Zinc	Melting	800-900
Zinc Alloy	Die Casting	850

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FUEL CONSUMPTION OF TYPICAL FURNACES

Brick, kilns:	Btu/1000 Brick
Hoffman continuous kiln	3,920,000-4,760,000
Ruebon kiln	5,880,000-9,240,000
Grates and trough	4,760,000-6,300,000
Staffordshire kiln	4,760,000-6,300,000
Buhrer continuous tunnel	3,220,000-3,900,000
Metal melting:	Btu/Ton
Iron and steel:	
Puddling	14,000,000
Open-hearth	3,000,000-6,500,000
Air furnace for malleable castings	8,600,000
Copper, reverberatory	4,200,000
Tin, smelting	19,200,000
Rolling-mill furnaces:	
Busheling	5,600,000-7,000,000
Billet heating	2,240,000-2,520,000
Billet heating (4 by 4)	2,800,000-4,200,000
Continuous furnace (cold billets)	1,500,000-2,250,000
Continuous-bloom furnace	1,400,000-2,100,000
Reheating cold blooms	1,960,000-2,800,000
Soaking pits (hot to cold ingots)	250,000-2,000,000
Tire furnaces	4,500,000
Wheel furnaces	8,400,000
Sheet annealing	2,800,000
Tin-plate mill	2,500,000
Rivet making:	
Rivet-making furnaces	1,260,000
Forging:	
Drop forging or bolt heating	6,000,000-7,000,000
Ingot forging	4,000,000-5,000,000
Ingot forging (regeneration furnace)	3,500,000-4,000,000
Brass annealing	1,500,000-2,000,000
Heat-treatment:	
Casehardening	4,500,000-5,000,000
Quenching	2,000,000-3,000,000
Tempering	1,500,000-2,000,000

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AVERAGE ECONOMY OF INDUSTRIAL FURNACES WITH GOOD OPERATION

PROCESS	Millions of Btu per Net Ton	Efficiency Per Cent
FERROUS PRODUCTS		
Ingot heating, soaking pits	1.0	24
Billet heating for forming Batch –		
In-and-out type	3.5	20
Continuous non-recuperative	2.2	32
Bar annealing, pit or car type	2.6	17
Wire annealing – hood type, coils	2.7	16
strand in lead	2.2	19
strand, open fired	1.2	32
stainless, catenary strand	2.7	24
Caustic pickle, stainless wire coils	0.7	26
Wire temper, open heat, lead quench	4.0	19
Wire patenting, strands	2.5	20
Wire galvanizing, strands	0.8	30
Wire tinning, strands	0.4	35
Wire baking, coils, continuous	0.5	32
Nail galvanizing, retort	0.3	—
Nail blueing, continuous retort	0.4	—
Tube reheating, sizing mill	1.5	18
Tube annealing – Continuous, bright	1.2	35
Batch, car type	1.5	28
Tube normalizing, continuous roll-down	1.7	33
Tube galvanizing	1.2	20
Skelp heating, butt weld – batch	3.8	20
continuous	3.0	25
Slab heating, continuous recuperative	1.6	43
Sheet bar heating – batch	2.2	22
continuous	1.7	29
Sheet and strip annealing, hood type –		
Carbon steels	1.2	27
Alloy steels	2.0	19
Strip annealing, continuous, coils	1.6	24
Strip, bright annealing, strands	1.2	32
Sheet normalizing, continuous, wasters	3.5	17
Sheet galvanizing	1.0	24
Nickle stainless sheet anneal, strands	3.0	21
Caustic pickle stainless strip, continuous	0.3	—
Nickle stainless sheet anneal, batch	4.5	16
Enamelling – Cast iron, three coats, batch	4.0	21
Flat ware, continuous	2.6	18
Hardening, continuous conveyor type	2.5	20
Drawing, continuous conveyor type	1.5	21
Carburizing, boxes, continuous	4.5	12
Carburizing, gas, continuous	3.0	18
Annealing steel castings	3.7	13
NON-FERROUS PRODUCTS		
Copper and brass –		
Billet or cake heating, continuous	0.8	30
Wire annealing – coils, continuous	1.5	16
strands, bright	1.1	22
Sheet and strip anneal, continuous, pans	0.8	30
Cartridge case anneal, continuous	1.3	19
Aluminum –		
Billet heating	1.4	32

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COMPARISON OF REFRACTORIES

Chemical Classification of Refractories[1]

Acidic refractories	Fireclay
	Silica
Basic refractories	Magnesia
	Zirconia
Amphoteric refractories	Alumina
Neutral refractories	Chromite
	Graphite
	Carbon
	Carborundum and allied compounds

[1] A. B. Searle, "Refractory Materials."

GAS SAVINGS WITH PREHEATED AIR

1. The heat salvaged by recuperation may be utilized by any of the following means depending upon the process involved.
   a. The volume of gas used for a given job may be decreased.
   b. Production may be increased because of the greater quantity of heat available.
   c. Temperatures of the furnace may be increased.

2. Mathematical formulae is given below have been established for calculating the possible gas savings and theoretical probable increase in production due to preheated air:
   a. Formula for gas savings calculation

$$S = \frac{A}{G - F_G + A} \times 100.$$

   S = per cent gas savings.
   A = heat in air, Btu per cu.ft. of gas.
   G = Average gross heating value of gas per cu.ft.
   F_G = flue loss above room temperature including latent heat of vaporization, Btu, per cu.ft. of gas.
   b. Formula for calculating possible increase in production.

$$S_w = \frac{P}{W_1} \times 100.$$

Where
   S_w = percentage increase in work.
   P = heat introduced by preheated air, Btu per hr. above room temperature.
   W_1 = heat absorbed by work with no preheat, Btu per hr.

3. Experimental tests have verified the correctness of the formula for
   a. Natural and coke oven gases (or any city gas).
   b. Either reducing, neutral or oxidizing furnace atmospheres.
   c. Flue gas temperatures from 1,400–2,500° F.
   d. Preheated air temperatures from 80–1,624° F.

4. From the results obtained it is concluded that the formula given in (2) is correct for all industrial gas furnace applications.

5. Gas savings in excess of 40 per cent have resulted when burning natural gas with preheated air at approximately 1,600° F. The practicability of air preheated in excess of that temperature seems doubtful since the economic limit from the standpoint of investment for most installations would be exceeded.

With permission, "Surface Combustion Industrial Heating Handbook."

PHYSICAL CLASSIFICATION OF REFRACTORIES

Refractory	PCE	High temp strength	Spalling resistance	Iron oxide slagging resistance[a]	Remarks
Silica	31–32	Excellent	Sensitive below 600°C	Fair	Widely used for sprung arches because of high-temperature strength
Fireclay	19–34	Fair	Fair Depends on manufacture	Poor	General purpose material. Inexpensive
High-alumina	Above 38	Properties improve with increasing Al_2O_3			Used for more severe conditions than fireclay will withstand
Mullite	38	Excellent	Good	Good	
Magnesite	38 and above	Good	Sensitive. Depends somewhat upon manufacture	Superior	Expensive. Used in metallurgical furnaces. High heat capacity
Forsterite	Over 32	Excellent	Good	Excellent	Indicated where both high-temperature strength and resistance to slagging are needed
Chrome	38 and above	Good	Fair to good, depending on composition and manufacture	Excellent below 2800°F. Poor above that temp	Less expensive and somewhat less slag-resistant than magnesite. Same general type of applications
Silicon carbide	37 to above 38	Excellent	Superior	Fair to poor	Expensive. Used in contact with flames and for indirect heat transfer. Abrasion-resistant

[a] Resistance to slagging does not always control uses and applications. See last column under Remarks and context of chapter.

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REPRESENTATIVE FUSION TEMPERATURES OF REFRACTORIES

	Fusing Temp, °C, of Commercial Refractories
Fused alumina	1750–2000
Bauxite	1565–2000
Mullite	1650–1820
Fireclay	1500–1750
Silica	1685–1800
Silicon carbide	1800–2240
Magnesite	2150–2165
Chrome	1850–2050
Spinel ($MgO.Al_2O_3$)	2135

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STANDARD TWIST DRILL SIZES

Designation	Diam, in.	Area, sq in.	Designation	Diam, in.	Area, sq in.	Designation	Diam, in.	Area, sq in.
1/2	0.5000	0.1963	3	0.213	0.03563	3/32	0.0938	0.00690
31/64	0.4844	0.1843	4	0.209	0.03431	42	0.0935	0.00687
15/32	0.4688	0.1726	5	0.2055	0.03317	43	0.0890	0.00622
29/64	0.4531	0.1613	6	0.204	0.03269	44	0.0860	0.00581
7/16	0.4375	0.1503	13/64	0.2031	0.03241	45	0.0820	0.00528
27/64	0.4219	0.1398	7	0.201	0.03173	46	0.0810	0.00515
Z	0.413	0.1340	8	0.199	0.03110	47	0.0785	0.00484
13/32	0.4063	0.1296	9	0.196	0.03017	5/64	0.0781	0.00479
Y	0.404	0.1282	10	0.1935	0.02940	48	0.0760	0.00454
X	0.397	0.1238	11	0.191	0.02865	49	0.0730	0.00419
25/64	0.3906	0.1198	12	0.189	0.02806	50	0.0700	0.00385
W	0.386	0.1170	3/16	0.1875	0.02761	51	0.0670	0.00353
V	0.377	0.1116	13	0.185	0.02688	52	0.0635	0.00317
3/8	0.375	0.1104	14	0.182	0.02602	1/16	0.0625	0.00307
U	0.368	0.1064	15	0.1800	0.02545	53	0.0595	0.00278
23/64	0.3594	0.1014	16	0.1770	0.02461	54	0.0550	0.00238
T	0.358	0.1006	17	0.1730	0.02351	55	0.0520	0.00212
S	0.348	0.09511	11/64	0.1719	0.02320	3/64	0.0473	0.00173
11/32	0.3438	0.09281	18	0.1695	0.02256	56	0.0465	0.001698
R	0.339	0.09026	19	0.1660	0.02164	57	0.0430	0.001452
Q	0.332	0.08657	20	0.1610	0.02036	58	0.0420	0.001385
21/64	0.3281	0.08456	21	0.1590	0.01986	59	0.0410	0.001320
P	0.323	0.08194	22	0.1570	0.01936	60	0.0400	0.001257
O	0.316	0.07843	5/32	0.1563	0.01917	61	0.039	0.001195
5/16	0.3125	0.07670	23	0.1540	0.01863	62	0.038	0.001134
N	0.302	0.07163	24	0.1520	0.01815	63	0.037	0.001075
19/64	0.2969	0.06922	25	0.1495	0.01755	64	0.036	0.001018
M	0.295	0.06835	26	0.1470	0.01697	65	0.035	0.000962
L	0.29	0.06605	27	0.1440	0.01629	66	0.033	0.000855
9/32	0.2813	0.06213	9/64	0.1406	0.01553	67	0.032	0.000804
K	0.281	0.06202	28	0.1405	0.01549	1/32	0.0313	0.000765
J	0.277	0.06026	29	0.1360	0.01453	68	0.031	0.000755
I	0.272	0.05811	30	0.1285	0.01296	69	0.0292	0.000670
H	0.266	0.05557	1/8	0.1250	0.01227	70	0.028	0.000616
17/64	0.2656	0.05542	31	0.1200	0.01131	71	0.026	0.000531
G	0.261	0.05350	32	0.1160	0.01057	72	0.025	0.000491
F	0.257	0.05187	33	0.1130	0.01003	73	0.024	0.000452
E¼	0.2500	0.04909	34	0.1110	0.00968	74	0.0225	0.000398
D	0.246	0.04753	35	0.1100	0.00950	75	0.021	0.000346
C	0.242	0.04600	7/64	0.1094	0.00940	76	0.020	0.000314
B	0.238	0.04449	36	0.1065	0.00891	77	0.018	0.000254
15/64	0.2344	0.04314	37	0.1040	0.00849	78	0.016	0.000201
A	0.234	0.04301	38	0.1015	0.00809	1/64	0.0156	0.000191
1	0.228	0.04083	39	0.0995	0.00778	79	0.0145	0.000165
2	0.221	0.03836	40	0.0980	0.00754	80	0.0135	0.000143
7/32	0.2188	0.03758	41	0.0960	0.00724			

NOTE—Designations are in fractions of an inch, in standard twist drill letters, or in standard twist drill numbers, the latter being the same as steel wire gauge numbers. *(Courtesy of AGA.)*

COLOR SCALE FOR TEMPERATURES

(The following color scale permits a rough approximation of high temperatures)

Color	°C	°F
Lowest visible red	475	885
Lowest visible red to dark red	475– 650	885–1200
Dark red to cherry red	650– 750	1200–1380
Cherry red to bright cherry red	750– 815	1380–1500
Bright cherry red to orange	815– 900	1500–1650
Orange to yellow	900–1090	1650–2000
Yellow to light yellow	1090–1315	2000–2400
Light yellow to white	1315–1540	2400–2800
White to dazzling white	1540 or higher	2800 or higher

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COMPOSITION OF COMMON ALLOYS[1]

	Cu	Zn	Fe	Sn	Pb	Sb	Ni	Ag	Bi	Al	Remarks
Acid-resisting metal	83.05	6.00	.....	10.81	0.10	.....	.....	.....	.....	.....	Recommended for use with acid mine water
Admiralty brass	61.7	36.9	.....	1.4	.....	.....	.....	.....	.....	.....	Melts at 1570° F
Aich's metal	60.00	38.12	1.50	.....	.....	.....	.....	.....	.....	.....	This and Sterro's metal are remarkable for their great tensile strength, 85,000 lb per sq in.
Ajax plastic bronze	65.00	.....	.....	5.00	30.00						
Alkali-resisting metal	.....	.....	95.00	.....	.....	.....	5.00	.....	.....	.....	For soap factories, etc.
Anti-friction metal	5.00	85.00									
Ashberry	.....	2.80	.....	77.80	.....	19.40					
Babbitt's (original)	4.00	69.00	.....	19.00	5.00	3.00					
German railways	5.60	.....	.....	83.30	.....	11.10	.....	.....	.....	.....	S.A.E. specification says Sb, 9%; Cu, 7%
hard	8.00	.....	.....	88.00	.....	4.00					
normal	3.00	.....	.....	90.00	.....	7.00					
soft	3.00	.....	.....	84.00	5.60	7.40					
Swiss railways	10.00	.....	.....	80.00	.....	10.00					
Bell metal	80.00	.....	.....	20.00							
Berlin argentan	52.00	22.00	.....	.....	.....	.....	26.00				
Brass, cartridge	66.66	33.34	.....	.....	.....	.....	.....	.....	.....	.....	Yellow brass for plumbers' use may carry up to 4% lead in this mixture. Without lead melts at about 1650°
high	61.50	38.50	.....	.....	.....	.....	.....	.....	.....	.....	Typical brass. The high brass for naval use may carry 1% Sn, and melts at 1570°
low	80.00	20.00	.....	.....	.....	.....	.....	.....	.....	.....	
red	85.00	5.00	.....	5.00	5.00	.....	.....	.....	.....	.....	Melts at 1780° F
solder	33.00	67.00	.....	.....	.....	.....	.....	.....	.....	.....	Or may be 50% Cu, 50% Zn
Britannia, casting	0.20	.....	.....	90.60	.....	9.20	.....	.....	.....	.....	Some makers say 0.15% Mn improves the grain
sheet	1.50	.....	.....	90.60	.....	7.80					
spinning	1.00	.....	.....	94.00	.....	5.00					
Bronze, bearing metal	80.00	7.00	.....	13.00							
bearing metal	90.00	7.00	.....	3.00							
British coinage	95.00	1.00	.....	4.00							
Chinese art	74.00	10.00	.....	1.00	15.00						
Japanese art	82.70	1.80	.....	.....	4.70						
Japanese art	71.40	6.00	.....	.....	5.90						
leaded	80.00	.....	.....	10.00	10.00	.....	.....	.....	.....	.....	Melts at 1735° F
tobin	58.22	39.48	.....	2.30							
U. S. Naval	88.00	2.00	.....	10.00	.....	.....	.....	.....	.....	.....	Not over 0.3% Pb. English gear bronze is Cu 88.70, Sn 11.00, P 0.30
valve	90.00	6.00	.....	.....	4.00	.....	.....	.....	.....	.....	Material should be capable of being peened and hammered
Camelia metal	70.20	10.20	0.55	4.25	14.75						
Coin, silver, U. S	10.00	.....	.....	.....	.....	.....	.....	90.00			
Constantan	60.00	.....	.....	.....	.....	.....	40.00				
Cupromagnesium	90.00	.....	.....	.....	.....	.....	.....	.....	Mg 10.00	.....	Used as a deoxidizer; density 8.4, melts 1290° C
Darcet's metal	.....	.....	.....	25.00	25.00	.....	.....	.....	50.00	.....	Melts at 93° C
Delta metal	55.10	43.47	1.08	.....	0.37	.....	.....	.....	.....	.....	Practically same as Sterro's metal
Dewrance metal	22.2	.....	.....	33.3	.....	44.5					
Duralumin	3.00	.....	.....	.....	.....	.....	Mn 1.0	Mg 0.5	.....	95.5	May contain some Fe and Si from the Al
Fontaine-Moreau's bronze	4.50	94.00	0.50								
Fusible metal	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	See Darcet's, Guthrie's, Lipowitz's, Lichtenburg's, Newton's, Onion's, Rose's, Wood's metals
German silver (English)	61.30	19.10	.....	.....	.....	.....	Ni 19.10				
Gun metal	92.50	2.50	.....	5.00							
Gun metal	91.00	2.00	.....	7.00							
Gun metal	87.75	2.50	.....	9.75	.....	.....	.....	.....	.....	.....	Melts at 1825° F
Gun metal	85.00	10.00	.....	5.00	.....	.....	.....	.....	.....	.....	With 3% Pb, melts at 1795° F
Gun metal	83.00	15.00	.....	2.00							
Gurley's metal	86.50	5.40	.....	5.40	2.70	.....	.....	.....	.....	.....	Used for transit frames
Guthrie's metal	.....	.....	.....	19.97	19.36	.....	.....	Cd 13.29	47.38	.....	Melts at 160° F

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	Cu	Zn	Fe	Sn	Pb	Sb	Ni	Ag	Bi	Al	Remarks
Hardware metal	50.00	34.90	.....	.....	.....	.....	15.00	.....	.....	0.10	Harness trimmings, etc. Casts well. Doesn't roll
Hydraulic bronze	75.00	14.00	.....	11.00							
Hydraulic bronze	83.00	5.00	.....	5.00	5.00	.....	2.00	.....	.....	.....	For pressures up to 3000 lb per sq in.
Jacoby metal	5.00	.....	.....	85.00	.....	10.00					
Lichtenberg's metal	.....	.....	.....	20.00	30.00	.....	.....	.....	50.00	.....	Melts 94.5° C
Lipowitz's metal	.....	.....	.....	13.33	26.67	.....	.....	.....	50.00	Cd 10.00	Melts 70° C
Mackenzie's alloy	.....	.....	.....	.....	68.00	16.00	.....	.....	16.00	.....	Stereotype metal
Magnolia metal	.....	.....	.....	4.75	80.00	15.00	.....	.....	0.25	.....	Melts at 608° C., coeff. of exp. 0.000024 per C°
Manganese bronze	88.64	1.57	0.72	8.70	0.295	.....	.....	.....	.....	.....	Trace of phosphorus
Manganin	82.12	.....	0.57	.....	.....	.....	2.29	.....	Mn 15.02	.....	Practically no temperature coefficient of resistance
Mannheim gold	80.00	20.00	.....	.....	.....	.....	.....	.....	.....	.....	Practically identical with Prince's metal and Tombac
Mannheim gold	88.00	12.00									
Monel metal	33.00	.....	6.50	.....	.....	.....	60.00	.....	.....	Al 0.05	U. S. Government specifications for castings
Morin's Chinese bronze	83.00	2.00	.....	5.00	10.00						
Mosaic gold	65.00	35.00									
Muntz metal	62.00	38.00									
Muntz metal	60.00	40.00									
Needle metal	84.96	5.31	.....	7.96	1.77	.....	.....	.....	.....	.....	Extremely fluid
Newton's metal	.....	.....	.....	18.75	31.25	.....	.....	.....	50.00	.....	Melts at 94.5° C
Onion's alloy	.....	.....	.....	20.00	30.00	.....	.....	.....	50.00	.....	Melts at 197° F
Packfong	43.80	40.60	.....	.....	.....	.....	15.60	.....	.....	.....	A Chinese alloy
Parr's alloy	5.00	.....	Cr 20.00	.....	.....	.....	63.00	W 2.00	.....	Mo 5.00	Also contains Al, B, and Mn. Said to have tensile strength of 60,000 lb per sq in. and to resist acids
Pewter	1.42	.....	.....	97.00	1.65						
Phosphor bronze	80.00	.....	.....	10.00	10.00	.....	.....	.....	.....	.....	Phosphorus, 0.05–0.25%
Pinchbeck	83.33	16.76	.....	.....	.....	.....	.....	.....	.....	.....	A cheap imitation gold
Plastic bronze	65.00	.....	.....	5.00	30.00						
Platine	43.00	57.00									
Platinoid	60.00	24.00	.....	.....	.....	.....	14.00	W 2.00			
Queen's metal	3.50	0.90	.....	88.50	.....	7.10					
Red metal	70.00	20.00	.....	4.00	6.00	.....	.....	.....	.....	.....	Melts at about 1800° F
Rose's metal	.....	.....	.....	25.00	25.00	.....	.....	.....	50.00	.....	Melts at 93.75° C
Sheffield German silver	57.00	19.00	.....	.....	.....	.....	24.00				
Silicon bronze	97.12	1.12	.....	1.14	.....	.....	.....	.....	.....	.....	Also a little silicon. Extremely high tensile strength
Solder	.....	.....	.....	33.33	66.67	.....	.....	.....	.....	.....	Sp gr 9.4; coeff. of exp., 0.000025 per °C; melts at 240° C
for German silver	45.00	45.00	.....	.....	.....	.....	10.00	.....	.....	.....	Melts easily, flows well
hard for silver	13.00	7.00	.....	.....	.....	.....	.....	80.00			
soft for silver	28.00	11.00	.....	4.00	.....	.....	.....	57.00			
Sterline	68.52	12.84	0.76	.....	tr.	17.88	.....	.....	.....	.....	Imitation silver for forks, etc.
Sterro's metal	55.33	41.80	4.66								
Tantiron	.....	.....	83.50	.....	C 1.0	.....	Si 15.0	.....	.....	.....	Highly resistant to corrosion by acid
Tobin bronze	58.22	39.48	.....	2.30							
Tombac, English	86.38	13.61									
Viennese	97.80	2.20									
Trolley-wheel bronze	92.00	2.00	.....	6.00	none						
Turbadium bronze	48.00	46.45	1.00	0.50	0.10	.....	2.00	Mn 1.75	.....	0.20	Used for propeller castings
Turbine-wheel mixture	86.77	3.48	.....	8.68	1.07	.....	.....	.....	.....	.....	Not so likely to have blow holes as Mn bronze
Type metal	.....	.....	.....	3.00	82.00	15.00					
Victor metal	49.94	34.27	0.28	.....	.....	.....	15.40	.....	.....	0.11	Resists salt air
Watchmaker's alloy	58.86	40.22	.....	.....	1.90	.....	.....	.....	.....	.....	An imitation gold
White brass	3–6	28–30	.....	65.00	.....	.....	.....	.....	.....	.....	Good bearing in automobile engines
Wood's metal	.....	.....	.....	12.50	25.00	.....	.....	Cd 12.50	50.00	.....	Melts at 60.5° C

[1]Liddell, "Metallurgists and Chemists' Handbook," McGraw-Hill

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PHYSICAL PROPERTIES OF METALS AND ALLOYS

Specific gravity, weight and volume

METAL OR ALLOY	Specific Gravity	Weight Lbs. per		Volume		METAL OR ALLOY	Specific Gravity	Weight Lbs. per		Volume	
		Cu. In.	Cu. Ft.	Cu. In. to 1 Lb.	Cu. Ft. to Ton 2000 Lbs.			Cu. In.	Cu. Ft.	Cu. In. to 1 Lb.	Cu. Ft. to Ton 2000 Lbs.
Aluminum, Cast	2.56	.092	160.0	10.87	12.50	Invar	7.99	.289	499.4	3.46	4.00
Aluminum, Sheet	2.67	.096	166.5	10.42	12.00	Iron, Gray, Cast	7.28	263	455.3	3.80	4.40
Aluminum, Wrought	2.71	.098	169.0	10.20	11.83	Iron, Swedish	7.79	.281	485.0	3.56	4.12
Antimony, Cast	6.70	.242	418.9	4.13	4.78	Iron, Wrought	7.79	.281	485.0	3.56	4.12
Bell Metal	8.70	.314	543.1	3.18	3.68	Lead, Cast	11.35	.411	709.5	2.43	2.82
Bismuth	9.74	.351	606.0	2.85	3.30	Lead, Sheet	11.40	.413	712.8	2.42	2.80
Brass - 80 Cu. 20 Zn.	8.60	.310	536.3	3.22	3.73	Magnalium	2.0	.072	125.0	13.88	16.06
Brass - 70 Cu. 30 Zn.	8.40	.3031	523.8	3.29	3.81	Magnesium	1.75	.064	109.0	15.62	18.35
Brass - 60 Cu. 40 Zn.	8.36	.3017	521.3	3.31	3.83	Manganese	8.00	.288	499.0	3.47	4.01
Brass - 50 Cu. 50 Zn.	8.20	.2959	511.4	3.38	3.91	Mercury, Fluid	13.57	.491	849.0	2.04	2.38
Brass, Red	8.75	.310	536.3	3.23	3.73	Molybdenum	10.20	.376	640.0	2.66	3.12
Brass, Sheet	8.53	.308	532.8	3.25	3.75	Monel Met. Cold Drawn	8.87	.321	555.6	3.11	3.60
Brass, White	8.30	.300	511.0	3.33	3.91	Nickel, Cast	7.81	.282	487.9	3.55	4.10
Brass, Wire	8.54	.308	533.0	3.25	3.75	Nickel, Hard Drawn	8.63	.311	537.0	3.21	3.72
Brass, Yellow	8.52	.305	526.9	3.28	3.79	Platinum, Sheet	21.40	.771	1342.0	1.30	1.49
Bronze, Manganese	8.22	.297	513.4	3.37	3.89	Silver, Pure	10.47	.379	654.6	2.64	3.05
Bronze, Phosphor	8.80	.317	549.4	3.30	3.63	Steel, Cast	7.83	.283	489.0	3.53	4.09
Bronze, Tobin	8.07	.291	505.0	3.44	3.96	Steel, Plate	7.83	.283	489.6	3.53	4.08
Cadmium	8.65	.312	539.0	3.20	3.71	Steel, Manganese	7.80	.282	487.5	3.54	4.10
Chromium	7.00	.253	437.0	3.96	4.08	Steel, Nickel	7.88	.284	491.0	3.52	4.07
Cobalt	8.73	.315	543.7	3.17	3.68	Steel, Stainless N (18-8)	7.86	.283	490.5	3.53	4.09
Constantan	8.90	.320	554.0	3.12	3.61	Steel, Stainless (25-12) Type 309	8.03	.290	502.0	3.45	3.99
Copper, Cast	8.61	.310	536.3	3.23	3.73	Steel, Tool	7.83	.283	489.6	3.53	4.08
Copper, Sheet	8.79	.317	548.0	3.15	3.65	Tantalum	16.65	.600	1036.3	1.66	1.93
Copper, Wire	8.88	.320	553.0	3.13	3.61	Tin, Cast	7.29	.264	455.7	3.79	4.39
German Silver	8.30	.300	518.1	3.33	3.86	Tungsten	18.65	.672	1161.1	1.49	1.71
Gold, Pure	19.26	.695	1200.9	1.44	1.67	Type Metal	10.45	.378	653.1	2.65	3.06
Gold, Hammered	19.36	.697	1217.0	1.43	1.64	Zinc, Cast	7.03	.254	439.3	3.94	4.55
Gun Metal	8.19	.295	509.6	3.39	3.93	Zinc, Rolled	7.20	.260	449.0	3.85	4.49

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THERMAL PROPERTIES OF METALS

Substance	Composition	Density lb/cu ft	Mean specific heat, 60°to melting point (Btu/lb)	Latent heat of fusion Btu/lb	Mean specific heat of liquid Btu/lb °F	Melting point °F	Average pouring temp °F	Ht content of solid at melting point Btu/lb	Ht content of liquid at melting temp Btu/lb	Ht content of liquid at pouring temp Btu/lb
Aluminum	Al	166.7	0.248	169.0	0.26	1215	1380	286.0	455.0	497.0
Babbitt, Lead Base	75 Pb, 15 Sb, 10 Sn	....	0.039	26.2	0.038	462	625	15.8	42.0	48.0
Babbitt, Tin Base	83.3 Sn, 8.4 Sb, 8.3 Cu	462	0.071	34.1	0.063	464	916	28.6	67.7	91.0
Bismuth	Bi	612	0.033	18.5	0.035	518	620	15.1	33.6	37.2
Brass, Muntz Metal	60 Cu, 40 Zn	524	0.105	69.0	0.125	1630	1850	165.0	234.0	261.0
Brass, Red	90 Cu, 10 Zn	546	0.104	86.5	0.115	1952	2250	197.0	283.5	317.8
Brass, Yellow	67 Cu, 33 Zn	528	0.105	71.0	0.123	1688	1950	171.0	242.0	274.2
Bronze, Aluminum	90 Cu, 10 Al	510	0.126	98.6	0.125	1922	2200	235.0	333.6	368.0
Bronze, Bearing	80 Cu, 10 Pb, 10 Sn	556	0.095	79.9	0.109	1832	2050	168.3	248.2	272.0
Bronze, Bell Metal	78 Cu, 22 Sn	540	0.100	76.3	0.119	1634	1900	157.4	233.7	265.4
Bronze, Gun Metal	90 Cu, 10 Sn	550	0.107	84.2	0.106	1850	2100	191.5	275.7	302.0
Bronze, Tobin	60 Cu, 39.2 Zn, 0.8 Sn	525	0.107	73.5	0.124	1625	1850	167.5	241.0	268.9
Copper	Cu	559	0.104	91.0	0.111	1982	2200	200.0	291.0	315.0
Die Casting Metal	92 Al, 8 Cu	176	0.236	163.0	0.241	1150	1400	257.3	420.3	481.0
Die Casting Metal	80 Pb, 10 Sn, 10 Sb	....	0.038	17.5	0.037	600	820	20.5	38.0	146.0
Die Casting Metal	90 Sn, 4.5 Cu, 5.5 Sb	....	0.070	30.2	0.062	450	650	27.6	57.8	70.0
Die Casting Metal	87.3 Zn, 8.1 Sn, 4.1 Cu, 0.5 Al	....	0.103	48.0	0.138	780	980	74.0	122.0	150.0
German Silver	60 Cu, 25 Zn, 15 Ni	....	0.109	86.2	0.123	1850	2100	194.0	280.2	311.0
Gold	Au	1205	0.033	28.5	0.034	1945	2150	62.2	90.7	97.7
Iron 60° to 2786° F	Fe	491	0.165	89.0	0.150	2786	2912	447.0	536.0	555.0
Lead	Pb	708	0.032	10.0	0.034	621	720	18.0	28.0	31.0
Linotype	86 Pb, 11 Sb, 3 Sn	....	0.036	21.5	0.036	486	620	15.3	36.8	41.6
Magnesium	Mg	108.6	0.272	83.7	0.266	1204	1380	311.2	394.9	441.7
Manganese	Mn	464	0.171	66.0	0.192	2246	2400	374.0	440.0	469.0
Monel Metal	67Ni, 28 Cu; Fe, Mn, Si	550	0.129	117.4	0.139	2415	2750	304.0	421.4	468.0
Nickel 60° to 2644 °F	Ni	556	0.134	131.5	0.133	2644	2850	346.0	477.5	505.0
Silver	Ag	655	0.063	46.8	0.070	1762	1950	107.0	153.8	167.0
Solder, Bismuth	40 Pb, 20 Sn, 40 Bi	....	0.040	16.4	0.039	232	330	9.3	25.7	29.5
Solder, Plumbers'	50 Pb, 50 Sn	580	0.051	23.0	0.049	414	500	18.0	41.0	45.0
Tin	Sn	455	0.069	25.0	0.0637	450	650	27.0	52.0	64.0
Zinc	Zn	445	0.107	48.0	0.146	786	900	77.8	125.8	142.0

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DESIRABLE HUMIDITIES FOR INDUSTRIAL OPERATIONS

Temperature varies (75°-85° F.)

Industry	*Process*	*Relative Humidity*
Cellulose	Processing and storage	35%
Confectionery	Hard candy making	40%
	Chewing gum rolling	50%
	Starch room	50%
Drugs	Powders and Tablets	30%
	Salts, Bromides and Alka Seltzer tablets	25%
Electrical	Manufacturers of electrical windings	40%
	Storage of electrical goods	40%
	Insulation windings (104° F.)	5%
Foods	Preparation of macaroni	38%
	Storage of sugar, gelatin	35%
Library or Museum	Book storage or paintings	40%
Paint	Air drying lacquers	40%
Paper	Storage and processing	40%
Photographic	Film drying	45%
Printing	Litho plate room (photo composing)	45%
	Press rooms	55%
Rubber	Dipping surgical articles	30%

DEGREE DAYS AND MINIMUM TEMPERATURES FOR CITIES OF UNITED STATES AND CANADA[1]

City	Min. temp.	Degree-days
Alabama		
Anniston	3	2813
Gadsden	—13	3006
Montgomery	— 5	1886
Ozark	10	1735
Tuscaloosa	— 7	2529
Arizona		
Flagstaff	—25	7145
Tucson	6	1845
Arkansas		
Bergman	—17	3956
Little Rock	—12	2811
Texarkana	— 7	2216
California		
Bakersfield	13	2047
Fresno	17	2375
Los Angeles	28	1504
Pasadena	21	2066
Sacramento	19	2654
San Diego	25	1645
San Francisco	29	3264
Colorado		
Buena Vista	—37	8849
Colorado Springs	—27	6553
Denver	—29	5873
Pueblo	27	5514
Connecticut		
Hartford	—18	6037
New Haven	—14	5895
Delaware		
Wilmington	—12	4788
District of Columbia		
Washington	—15	4626
Florida		
Monticello	16	1129
Tampa	9	296
Georgia		
Atlanta	— 8	2891
Augusta	3	2161
Macon	— 4	2203
Rome	— 7	3067
Savannah	8	1490
Idaho		
Boise	—28	4558
Springfield	—28	7477
Illinois		
Chicago	—23	6315
Joliet	—25	6535
Springfield	—24	5370
Indiana		
Evansville	—16	4164
Fort Wayne	—24	5916
Indianapolis	—25	5297
South Bend	—20	6076
Terre Haute	—18	4871
Iowa		
Davenport	—27	6287
Des Moines	—30	6373
Dubuque	—32	6788
Mason City	—35	7571
Sioux City	—35	7023
Kansas		
Emporia	—23	4792
Topeka	—25	5301
Wichita	—22	4877
Kentucky		
Lexington	—20	4616
Louisville	—20	4180
Louisiana		
Baton Rouge	2	1349
New Orleans	7	1023
Shreveport	— 5	1938
Maine		
Bar Harbor	—21	7643
Portland	—21	7012
Maryland		
Baltimore	— 7	4333
Frederick	No fig.	5928
Massachusetts		
Boston	—14	6145
Fitchburg	—17	6732
Williamstown	—26	7221
Michigan		
Ann Arbor	—21	6865
Cadillac	—36	7967
Detroit	—28	6494
Grand Rapids	—24	6534
Kalamazoo	—25	6652
Lansing	—26	7112
Sault Ste. Marie	—37	9281
Minnesota		
Duluth	—41	9480
Minneapolis	—33	7851
Rochester	—42	8123
Mississippi		
Columbia	9	1740
Corinth	— 8	3411
Tupelo	— 7	2780
Vicksburg	— 1	1809
Missouri		
Grant City	—29	5659
Jefferson City	—25	4874
Kansas City	—22	5202
St. Louis	—22	4585
Montana		
Billings	—49	7115
Butte	—33	8271
Helena	—42	8054
Nebraska		
Dumas	—31	7203
Omaha	—32	6128
Nevada		
Las Vegas	8	2842
Reno	—19	5891
New Hampshire		
Concord	—35	6852
Hanover	—37	8063
Keene	—28	7457
New Jersey		
Atlantic City	— 7	5175
Dover	—21	5970
Newark	—13	5387
New Brunswick	—15	5405
Sussex	—24	6134
Trenton	—13	4934
New Mexico		
Albuquerque	—10	4303
Santa Fe	—13	6063
New York		
Albany	—24	6889
Buffalo	—14	6821
Ithaca	—22	6719
New York City	—13	5348
Ogdensburg	—43	7490
Plattsburg	—25	7894
Rochester	—14	6733
Saranac Lake	—39	8673
Syracuse	—22	6592
North Carolina		
Asheville	No fig.	4263
Greensboro	— 3	3527
Wilmington	5	2302
North Dakota		
Bismarck	—45	8498
Hannah	—54	10714

(Continued on next page)

[1] From AGA "Househeating" and U.S. Weather Bureau.

City	Min. temp.	Degree-days
Ohio		
Akron	—20	6069
Cincinnati	—17	4702
Cleveland	—17	6154
Columbus	—20	5323
Dayton	—16	5274
Oklahoma		
Hugo	— 3	2648
Oklahoma City	—17	3613
Tulsa	—15	3560
Oregon		
Portland	— 2	4468
Wallowa	—38	7360
Pennsylvania		
Erie	—16	5866
Gettysburg	—20	5580
Philadelphia	— 6	4855
Pittsburgh	—20	5235
Reading	—14	5388
Scranton	—15	6129
Rhode Island		
Providence	—12	6014
South Carolina		
Charleston	7	1769
Columbia	— 2	2364
Spartanburg	— 4	3257
South Dakota		
Aberdeen	—46	8709
Jefferson	—48	8419
Tennessee		
Knoxville	—16	3670
Memphis	— 9	2950
Nashville	—13	3578
Texas		
Austin	— 1	1578
Dallas	—10	2455
Eagle Pass	— 7	871
Galveston	8	1016
Houston	6	1157
San Antonio	4	1202
Utah		
Provo	—23	6184
Salt Lake City	—20	5553
Vermont		
Burlington	—28	7620
Northfield	—41	8420
Virginia		
Fredericksburg	—21	4243
Roanoke	—12	4068
Richmond	— 3	3725
Washington		
Seattle	3	4868
Spokane	—30	6353
Walla Walla	—17	4809
West Virginia		
Charleston	—17	3786
Huntington	—24	4734
Wheeling	No fig.	5249
Wisconsin		
Green Bay	—36	7823
Milwaukee	—25	7372
Superior	—35	9750
Wyoming		
Casper	—30	6979
Cheyenne	—38	7462
Canada		
Vancouver, B. C.	...	5976
Winnipeg, Man.	...	11166
Toronto, Ont.	...	7732
Montreal, Que.	...	8705
Quebec, Que.	...	8628

AVERAGE RELATIVE HUMIDITY

STATION		Length of record (yrs.)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Ala.	Mobile	48	74	73	73	71	71	72	68	76	74	70	71	77	72
	Montgomery	46	70	67	64	62	62	64	70	72	67	64	66	71	67
Ariz.	Phoenix	42	48	47	39	31	25	23	35	41	38	38	43	50	38
Ark.	Little Rock	46	69	67	63	62	66	66	66	67	67	65	66	70	66
Calif.	Fresno	50	76	69	62	52	44	36	31	33	39	49	61	76	52
	Los Angeles	49	56	61	61	64	68	68	67	67	64	61	51	54	62
	San Francisco	44	75	72	70	70	72	74	79	80	74	70	69	74	73
Colo.	Denver	48	52	52	49	49	49	44	44	45	44	46	48	52	48
D. C.	Washington	36	66	63	61	59	65	69	71	70	71	71	66	68	67
Fla.	Jacksonville	54	74	72	69	67	69	72	74	75	77	75	74	75	73
	Miami	30	73	72	70	69	71	74	73	73	75	74	71	73	73
Ga.	Atlanta	38	72	69	66	63	64	67	73	74	71	67	67	72	69
Idaho	Boise	[1] 41	73	67	55	49	46	43	34	33	41	51	62	73	52
Ill.	Chicago	27	75	73	70	66	66	67	65	68	70	67	70	76	69
Ind.	Indianapolis	54	75	71	67	61	60	61	59	63	64	64	69	74	66
Iowa	Des Moines	50	70	77	72	65	65	68	66	70	72	70	73	78	71
Kans.	Wichita	54	70	65	59	58	63	61	57	57	60	60	64	70	62
Ky.	Louisville	48	72	69	65	61	61	62	62	64	65	63	67	71	65
La.	New Orleans	47	75	73	71	70	69	70	74	74	73	70	72	75	72
Maine	Eastport	48	74	74	73	74	76	79	82	81	80	77	77	75	77
Mass.	Boston	31	68	66	65	65	67	67	68	71	71	68	70	68	68
Mich.	Detroit	42	84	85	74	68	66	66	62	64	68	71	76	81	71
	Sault Ste. Marie	33	84	82	78	70	68	70	73	75	79	79	82	84	77
Minn.	Minneapolis	42	79	76	68	60	58	63	60	62	66	66	72	78	64
Miss.	Vicksburg	72	74	70	68	70	72	74	78	79	76	73	72	74	73
Mo.	Kansas City	38	72	69	65	63	65	66	61	64	66	63	66	72	66
	St. Louis	46	71	68	64	61	62	62	59	62	64	62	65	71	64
Mont.	Helena	57	68	66	58	53	52	50	43	44	51	57	64	68	56
	Miles City	[2] 50	75	73	68	57	53	54	47	48	54	61	70	75	61
Nebr.	North Platte	48	70	67	61	57	59	61	58	58	60	58	63	70	62
	Omaha	38	75	74	68	62	64	66	63	66	66	63	69	75	67
Nev.	Winnemucca	38	76	70	58	49	60	40	30	29	37	49	62	76	52
N. J.	Atlantic City	57	74	73	73	72	75	77	78	78	76	73	72	73	75
N. Mex.	Albuquerque	21	60	52	44	39	36	33	45	49	50	49	51	61	47
N. Y.	Albany	38	75	74	70	66	65	69	70	72	76	74	74	75	72
	New York	47	66	64	63	61	63	65	69	70	70	67	68	67	65
	Rochester	46	74	74	69	63	61	63	62	64	68	69	72	74	68
N. C.	Asheville	40	71	68	65	61	63	68	72	75	72	68	66	70	68
	Raleigh	57	73	71	69	66	68	72	76	79	78	74	71	74	72
N. Dak.	Bismarck	56	76	75	69	59	57	61	57	56	60	63	72	76	66
Ohio	Cleveland	52	59	58	59	58	61	64	65	66	66	66	58	59	61
Okla.	Oklahoma City	36	71	68	62	63	68	68	62	62	64	66	66	71	66
Oreg.	Portland	48	81	77	71	65	64	63	60	62	66	74	80	81	70
Pa.	Harrisburg	56	68	65	62	56	58	63	63	65	66	66	64	65	64
	Pittsburgh	49	73	73	67	62	61	64	63	65	66	67	70	77	67
S. C.	Charleston	52	70	65	63	65	65	78	78	78	77	77	72	78	72
S. Dak.	Huron	56	78	77	69	61	58	62	58	59	60	62	70	77	66
Tenn.	Nashville	38	75	70	66	62	66	67	68	71	70	67	69	73	69
Tex.	Amarillo	52	60	57	50	49	56	54	52	54	57	58	57	61	55
	El Paso	55	44	38	30	25	25	28	41	45	44	42	43	48	38
	Fort Worth	34	67	66	59	62	64	61	58	58	61	63	64	69	63
	Houston	33	75	74	72	73	74	73	74	73	74	70	71	75	73
Utah	Salt Lake City [3]	13	80	74	62	54	47	45	38	39	43	56	71	77	57
Vt.	Burlington	38	80	81	77	72	70	73	75	77	81	79	79	81	77
Va.	Norfolk	8	72	69	68	67	71	74	77	77	77	74	71	72	72
	Richmond	47	72	67	64	61	64	67	70	72	72	69	67	71	68
Wash.	Seattle	39	81	80	73	68	67	66	66	69	72	79	82	82	73
	Spokane	54	82	75	62	52	49	47	38	40	50	62	78	83	60
W. Va.	Parkersburg	37	76	74	68	64	67	72	71	74	74	72	72	76	72
Wis.	Madison	37	81	79	73	65	64	67	64	67	70	70	76	82	71
Wyo.	Cheyenne	41	55	58	57	58	56	53	48	49	49	50	51	55	53
Alaska	Juneau	26	77	74	70	69	70	70	78	81	81	82	77	77	76
T. H.	Honolulu	33	70	70	68	67	67	66	66	67	67	68	69	71	68
P. R.	San Juan [4]	47	81	80	77	76	77	77	78	78	79	79	81	81	79

"Statistical Abstract of the United States." U. S. Department of Commerce.

ANNUITY WHICH WILL AMOUNT TO ONE DOLLAR IN A GIVEN TIME

ANNUITY APPLIED AT END OF EACH YEAR

Years	2 per cent	2½ per cent	3 per cent	3½ per cent	4 per cent	4½ per cent	5 per cent
1	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000
2	0.495050	0.493827	0.492611	0.491400	0.490196	0.488998	0.487805
3	.326755	.325137	.323530	.321934	.320349	.318773	.317209
4	.242624	.240818	.239027	.237251	.235490	.233744	.232012
5	.192159	.190247	.188355	.186481	.184627	.182792	.180975
6	.158526	.156550	.154597	.152668	.150762	.148878	.147017
7	.134512	.132495	.130506	.128545	.126610	.124701	.122820
8	.116510	.114467	.112456	.110477	.108528	.106610	104722
9	.102515	.100457	.098434	.096446	.094493	.092574	.090690
10	.091327	.089259	.087231	.085241	.083291	.081379	.079505
11	.082178	.080106	.078077	.076092	.074149	.072248	.070389
12	.074560	.072487	.070462	.068484	.066552	.064666	.062825
13	.068118	.066048	.064030	.062062	.060144	.058275	.056456
14	.062602	.060537	.058526	.056571	.054669	.052820	.051024
15	.057825	.055766	.053767	.051825	.049941	.048114	.046342
16	.053650	.051599	.049611	.047685	.045820	.044015	.042270
17	.049970	.047928	.045953	.044043	.042199	.040418	.038699
18	.046702	.044670	.042709	.040817	.038993	.037237	.035546
19	.043782	.041761	.039814	.037940	.036139	.034407	.032745
20	.041157	.039147	.037216	.035361	.033582	.031876	.030243
21	.038785	.036787	.034872	.033037	.031280	.029601	.027996
22	.036631	.034647	.032747	.030932	.029199	.027546	.025971
23	.034668	.032696	.030814	.029019	.027309	.025682	.024137
24	.032871	.030913	.029047	.027273	.025587	.023987	.022471
25	.031220	.029276	.027428	.025674	.024012	.022439	.020952
26	.029699	.027769	.025938	.024205	.022567	.021021	.019564
27	.028293	.026377	.024564	.022852	.021239	.019719	.018292
28	.026990	.025088	.023293	.021603	.020013	.018521	.017123
29	.025778	.023891	.022115	.020445	.018880	.017415	.016046
30	.024650	.022778	.021019	.019371	.017830	.016392	.015051
31	.023596	.021739	.019999	.018372	.016855	.015443	.014132
32	.022611	.020768	.019047	.017442	.015949	.014563	.013280
33	.021687	.019859	.018156	.016572	.015104	.013745	.012490
34	.020819	.019007	.017322	.015760	.014315	.012982	.011755
35	.020002	.018206	.016539	.014998	.013577	.012270	.011072
36	.019233	.017452	.015804	.014284	.012887	.011606	.010434
37	.018507	.016741	.015112	.013613	.012240	.010984	.009840
38	.017821	.016070	.014459	.012982	.011632	.010402	.009284
39	.017171	.015436	.013844	.012388	.011061	.009856	.008765
40	.016556	.014836	.013262	.011827	.010523	.009343	.008278
41	.015972	.014268	.012712	.011298	.010017	.008862	.007822
42	.015417	.013729	.012192	.010798	.009540	.008409	.007395
43	.014890	.013217	.011698	.010325	.009090	.007982	.006993
44	.014388	.012730	.011230	.009878	.008665	.007581	.006616
45	.013910	.012268	.010785	.009453	.008262	.007202	.006262
46	.013453	.011827	.010363	.009051	.007882	.006845	.005928
47	.013018	.011407	.009961	.008669	.007522	.006507	.005614
48	.012602	.011006	.009578	.008306	.007181	.006189	.005318
49	.012204	.010623	.009213	.007962	.006857	.005887	.005040
50	.011823	.010258	.008865	.007634	.006550	.005602	.004777

(Continued on next page)

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ANNUITY WHICH WILL AMOUNT TO ONE DOLLAR IN A GIVEN TIME (Concluded)

ANNUITY APPLIED AT END OF EACH YEAR

Years	5½ per cent	6 per cent	6½ per cent	7 per cent	8 per cent	9 per cent	10 per cent
1	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000
2	0.486618	0.485437	0.484262	0.483092	0.480769	0.478469	0.476190
3	.315654	.314110	.312576	.311052	.308034	.305055	.302115
4	.230295	.228591	.226903	.225228	.221921	.218669	.215471
5	.179173	.177396	.175635	.173891	.170456	.167092	.163797
6	.145179	.143363	.141568	.139796	.136315	.132920	.129607
7	.120964	.119135	.117331	.115553	.112072	.108691	.105405
8	.102864	.101036	.099237	.097468	.094015	.090674	.087444
9	.088839	.087022	.085238	.083486	.080080	.076799	.073641
10	.077668	.075868	.074105	.072378	.069029	.065820	.062745
11	.068571	.066793	.065055	.063357	.060076	.056947	.053963
12	.061029	.059277	.057568	.055902	.052695	.049651	.046763
13	.054684	.052960	.051283	.049651	.046522	.043567	.040779
14	.049279	.047585	.045940	.044345	.041297	.038433	.035746
15	.044626	.042963	.041353	.039795	.036830	.034059	.031474
16	.040583	.038952	.037378	.035858	.032977	.030300	.027817
17	.037042	.035445	.033906	.032425	.029629	.027046	.024664
18	.033920	.032357	.030855	.029413	.026702	.024212	.021930
19	.031150	.029621	.028156	.026753	.024128	.021730	.019547
20	.028679	.027185	.025756	.024393	.021852	.019546	.017460
21	.026465	.025005	.023613	.022289	.019832	.017617	.015624
22	.024471	.023046	.021691	.020406	.018032	.015905	.014005
23	.022670	.021278	.019961	.018714	.016422	.014382	.012572
24	.021036	.019679	.018398	.017189	.014978	.013023	.011300
25	.019549	.018227	.016981	.015811	.013679	.011806	.010161
26	.018193	.016904	.015695	.014561	.0125071	.0107154	.0091590
27	.016952	.015697	.014523	.013426	.0114481	.0097349	.0082576
28	.015814	.014593	.013453	.012392	.0104889	.0088520	.0074510
29	.014769	.013580	.012474	.011449	.0096185	.0080557	.0067281
30	.013805	.012649	.011577	.010586	.0088274	.0073364	.0060792
31	.012917	.011792	.010754	.009797	.0081073	.0066856	.0054962
32	.012095	.011002	.009997	.009073	.0074508	.0060962	.0049717
33	.011335	.010273	.009299	.008408	.0068516	.0055617	.0044994
34	.010630	.009598	.008656	.007797	.0063041	.0050766	.0040737
35	.009975	.008974	.008062	.007234	.0058033	.0046358	.0036897
36	.009366	.008395	.007513	.006715	.0053447	.0042350	.0033431
37	.008800	.007857	.007005	.006237	.0049244	.0038703	.0030299
38	.008272	.007358	.006535	.005795	.0045389	.0035382	.0027469
39	.007780	.006894	.006099	.005387	.0041851	.0032356	.0024910
40	.007320	.006462	.005694	.005009	.0038602	.0029596	.0022594
41	.006891	.006059	.005318	.004660	.0035615	.0027079	.0020498
42	.006489	.005683	.004968	.004336	.0032868	.0024781	.0018600
43	.006113	.005333	.004644	.004036	.0030341	.0022684	.0016880
44	.005761	.005006	.004341	.003758	.0028015	.0020767	.0015322
45	.005431	.004700	.004060	.003500	.0025873	.0019017	.0013910
46	.005122	.004415	.003797	.003260	.0023899	.0017416	.0012620
47	.004831	.004148	.003553	.003037	.0022080	.0015952	.0011468
48	.004559	.003897	.003325	.002831	.0020403	.0014614	.0010415
49	.004302	.003664	.003112	.002639	.0018856	.0013389	.0009459
50	.004061	.003444	.002914	.002460	.0017429	.0012269	.0008592

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INTERCHANGEABILITY OF VARIOUS GASES

BY interchangeability of gases is meant the possibility of using a substitute gas for the gas usually distributed for domestic and industrial consumption without interfering with the operation of appliances used by the consumer.

The subject is complicated by many factors such as heating value, specific gravity, and composition of the various gases under consideration.

The present supply of natural gas has resulted and probably will continue to result in the distribution in many cities of gases of rather high heating value; in many cases, of straight natural gas having a heating value in excess of 1000 Btu per cubic foot.

The American Gas Association has conducted considerable research on the general subject of interchangeability of gases. When it began reviewing the subject of a substitute gas for straight natural gas, it was found that none of the formulae developed earlier for the interchangeability of mixed gases of lower heating value were applicable to the interchangeability of the higher heating value gases. It became necessary to find new equations which would take into consideration all factors affecting interchangeability.

Interchangeability Factors

It was concluded that interchangeability of higher heating-value gases could be best mathematically treated if considered from three distinct viewpoints, that is, the tendency of high heating value supplemental gases to—

(1) lift

(2) flashback

(3) produce yellow tips.

The speed of flame propagation, or ignition velocity, is very important in consideration of the burning characteristics of different gases.

Fast-burning constituents, such as hydrogen and acetylene, accelerate the rate of flame propagation with a tendency toward flashback, whereas slow-burning constituents, such as methane and illuminants, produce little tendency to flashback but may result in lifting of the flame.

An equation to predict occurrence of lifting as a result of interchange of gases was developed which takes into consideration change in input-rate and primary-air injection resulting from the substitution as well as differences in lifting characteristics of the two gases. The index of lifting interchangeability, I_L, is the result obtained from calculation of the lifting interchangeability equation—

$$I_L = \frac{K_a}{\frac{f_s}{f_a}\,\frac{a_s}{a_a}\left(K_s\text{-log}\,\frac{f_s}{f_a}\right)}$$

An empirical expression was developed to denote the tendency of burners to flashback as a result of interchanging a supplemental gas for natural gas. The index of flashback interchangeability, I_F, is the result obtained from calculation of the flashback interchangeability equation—

$$I_F = \frac{K_s}{K_a}\,\frac{f_s}{f_a}\,\sqrt{\frac{h_s}{1000}}$$

An equation was developed for determining conditions of interchange which would result in yellow-tip formation. This equation takes into consideration changes in primary-air injection and yellow-tip limit resulting from substitution of one gas for another. Calculation of this equation gives value for the index of yellow-tip interchangeability, I_Y.

$$I_Y = \frac{f_s}{f_a}\,\frac{a_s}{a_s}\,\frac{Y_a}{Y_s}$$

Values For Equation Characters

In order to obtain values for the characters in these three equations, certain other equations must be employed, as follows:

Air theoretically required for complete combustion,

$$\text{per 100 Btu } a_a = \frac{100\,A_a}{h_a}$$

$$\text{Primary air factor } f_a = \frac{1000\sqrt{d_a}}{h_a}$$

$$\text{Lifting limit constant } K_a = \frac{F_a}{d_a}$$

Yellow-tip limit

$$Y_a = \frac{100\,T_a}{A_a + 7E_a - 26.3\,0_{2a}}$$

The nomenclature for the above equations follows—

- A = air theoretically required for complete combustion, cubic feet per foot of gas
- a = air theoretically required for complete combustion, cubic feet per 100 Btu of gas
- d = specific gravity (air = 1.0)
- E = total inerts in gas mixture, decimal volume
- F = lifting constant
- f = primary-air factor
- h = gross heating value, Btu per cubic foot
- I_F = index of flashback interchangeability
- I_L = index of lifting interchangeability
- I_Y = index of yellow-tip interchangeability
- K = lifting-limit constant
- O_2 = oxygen in gas mixture, decimal volume
- T = yellow-tip constant, cubic feet of air required to eliminate yellow tips per cubic foot of gas
- Y = yellow-tip limit, percent primary air

Subscript a = adjustment gas

Subscript s = substitute (or supplemental) gas.

Type of Natural Gas Distributed

In this work the American Gas Association assumed that one of the three types of natural gas presented below would be the adjustment gas or the gas normally distributed.

	High Btu Nat. Gas	High Methane Nat. Gas	High Inert Nat. Gas
Carbon dioxide . CO_2	0.5%	0.0%	0.5%
Methane . . . . . CH_4	83.0	94.5	71.4
Ethane . . . . . C_2H_6	16.0	0.0	14.0
Propane . . . . . C_3H_8	0.0	0.0	1.0
Nitrogen . . . . . N_2	0.5	5.5*	13.1
B.t.u./cu. ft. . . .	1115	959	1000
Sp. gr.	0.64	0.56	0.69

* Inerts.

For any proposed adjustment, or substitute gas, all three indices must fall within certain numerical limits, which are shown in an accompanying table:

It is stated that when burners are properly adjusted on the base-load gas, these preferable limits can be exceeded, the degree of variation depending on the adjustment natural gas.

When values of the Interchangeability Indices are intermediate between the preferable limit and the objectionable limit, each particular situation must be carefully analyzed to determine the limits of interchangeability.

The same formulae given can be used to determine the percentage of adjustment gas which must be retained in admixture with the supplemental gas to bring values of the Interchangeability Indices within desirable limits.

Appliance Tests Made

In arriving at the formulae given here, the American Gas Association Laboratories selected many critical appliances and adjusted them for a given type of natural gas. Substitute gases were then prepared and supplied to the appliances and observations made of the operating characteristics of each burner. If complete substitution of the supplemental gas resulted in unsatisfactory performance of any of the control appliances, further studies were made with portions of the base natural gas added to the supplemental gas. In this manner the limiting percentage of supplemental gas could be determined.

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Interchangeability Index	High-Heating Value Nat. Gas		High-Methane Nat. Gas		High-Inert Nat. Gas	
	Preferable	Objectionable	Preferable	Objectionable	Preferable	Objectionable
I_L	Under 1.0	Above 1.12	Under 1.0	Above 1.06	Under 1.0	Above 1.03
I_F	Under 1.18	Above 1.2	Under 1.18	Above 1.2	Under 1.18	Above 1.2
I_Y	Above 1.0	Under 0.7	Above 1.0	Under 0.8	Above 1.0	Under 0.9

In this same reference a comparison is given of a burner operating on the high Btu natural gas compared to carbureted water gas of 1000 and 1200 Btu per cubic foot. It is stated that only 40 per cent of these carbureted water gases could be mixed with the original natural gas and still maintain satisfactory combustion characteristics.

Base and Supplemental Gases

It is apparent that no generalized statement can be made regarding the interchangeability of high heating-value substitute gases with natural gas. Rather, it is necessary to make a very careful comparison of the proposed supplemental gas with the base, or adjustment gas.

In order to demonstrate the manipulation of the equations outlined, a comparison has been made using as a base, or adjustment gas, a natural gas, the analysis of which is given below. It is proposed to substitute for this a high Btu oil gas of the characteristics listed—

	Natural Gas	High Btu Oil Gas
Carbon dioxide ... CO_2	0.8%	6.4%
Illuminants	0.0	25.9
Oxygen ..... O_2	0.0	0.5
Carbon monoxide . CO	0.0	0.8
Methane ..... CH_4	91.0	33.3
Ethane ..... C_2H_6	3.1	0.0
Propane ..... C_3H_8	1.7	0.0
Butane ..... C_4H_{10}	0.7	0.0
Hydrogen ..... H_2	0.0	13.4
Nitrogen ..... N_2	2.7	19.7
B.t.u./cu. ft.	1047	970
Sp. gr.	0.61	0.88

Results were as follows:

	I_L Lifting Index	I_F Flash-back Index	I_Y Yellow-tip Index
100% Supplemental Gas	1.25	1.29	0.6
50% Supplemental Gas 50% Adjustment Gas	1.11	1.16	0.7
30% Supplemental Gas 70% Adjustment Gas	1.07	1.10	0.8

By comparison, it is seen that 100 per cent of this particular supplemental gas could not be used to replace natural gas of the type considered, since all three indices, Lifting, Flashback, and Yellow-Tip, are in the objectionable range. The mixture of 50 per cent oil gas with 50 per cent natural gas appears to be satisfactory from the standpoint of flashback. The Lifting Index and Yellow-Tip Index are almost exactly at the objectionable limits, so close that more natural gas is desirable. The mixture of 30 per cent oil gas with 70 per cent natural gas gives indices, none of which are in the objectionable range and which, in general, approximate the preferable range.

Percent of Oil Gas in Admixture

Accordingly, it is considered that 30 per cent of this oil gas could safely be used in admixture with the natural gas available. Possibly this proportion of oil gas could be exceeded, but probably not beyond 50 per cent. The proportion of this oil gas which can be used would probably be increased if the oil gas were scrubbed to remove some undesirable constituents.

The particular oil gas used in the foregoing discussion is one which has been proposed as a supplement or substitute for natural gas. The analysis used has been published. This gas is not necessarily the best or only substitute for natural gas. It is used merely to illustrate the application of equations derived for determining the interchangeability of gases of high heating-value. Later research may show that oil gases, or other gases, may be more nearly interchangeable with natural gas than is indicated by present knowledge on the subject.

A recent statement regarding research sponsored by the American Gas Association states:

> "Just initiated is a project to determine the approximate degree of compatibility of the currently produced oil gases with natural gas. These tests should indicate what further research is necessary to develop suitable substitutes for natural gas. It is possible that suitable control of the production processes will be sufficient. Possibly after-treatment with catalysts will provide the answers. Decisions as to the course of the future work must await the results of these preliminary studies."

For interchangeability of gases where the heating value of the send-out gas is rather low, in the neighborhood of 530-540 Btu other determinations have been made.

AGA "Index C" Method

In 1933 the American Gas Association, after considerable testing, evolved the so-called "Index C" calculated from a mathematical equation involving heating value, specific gravity, and chemical analysis of the base and supplemental gases. This "Index C" was supposed to be a criterion of interchangeability of gases with heating values below 700 Btu per cubic foot. If the supplemental gas had a "C" index in the range 0.85 to 1.15, it was indicated that it could replace the base gas and maintain satisfactory appliance performance. The equation is—

$$C = \frac{h_s}{h_a}\frac{A_s}{A_a}\frac{d_a}{d_s} + (K_a - K_s)$$

where,

C = index of interchangeability
a = subscript denoting adjustment gas
s = subscript denoting substitute gas
h = gross heating value, Btu per cubic foot
A = air theoretically required for complete combustion, cubic feet per cubic foot of gas
d = specific gravity of gas (air = 1.0)

$K = \frac{hA}{5000\,E\,F}$, in which

E = the heat capacity of the theoretical products of combustion (from one cubic foot of gas) per degree F. between 60°F. and 1600°F., in Btu E is equal to 0.029 VCO_2 + 0.023 VH_2O + 0.0189 VN_2 where V is the volume in cubic feet of each product (as indicated by the subscripts) formed by the combustion of one cubic foot of gas with the air theoretically required for complete combustion. The values 0.029, 0.023 and 0.0189 are, respectively, the heat capacities per degree F. of CO_2, H_2O and N_2, between 60°F. and 1600°F. in Btu per cubic foot.

F = Summation of the products of the mole fractions and some constant for each combustible constituent in the gas.

Objections to "Index C" Cited

Several objections have been cited against the use of "Index C" in some cases. The formula is quite satisfactory for the usual mixtures involving the normal manufactured gases, although it does not apply for mixtures in which the percentage of inerts exceeds the free-hydrogen content. It is also applicable in the comparison of many natural gases, but it is not generally applicable for mixtures involving adjustment and substitute gases of widely differing heating value or chemical composition unless the fraction of such radically differing gas in the substitute mixture does not exceed about 12 per cent. Thus the formula does not hold for such substitute mixtures as propane or butane and air, of natural gas-inert mixtures, etc., when substituted for the usual low-Btu manufactured city-gas, but it is satisfactory if the high heating-value hydrocarbon does not exceed

about 12 per cent in the final substitute mixture. The formula does not usually apply in cases involving the use of large amounts of oil gases as substitutes for natural gas. It was, in fact, found to be not fully applicable for gases of heating values higher than 800 Btu per cubic foot since the equation has no factors which predict the occurrence of yellow tips or lifting.

In 1946, the American Gas Association started a new series of tests on the interchangeability of gases of relatively low heating-value. The entire project is designated as TL-1.

Summarization of Aims, Results

The aims and results of this research by American Gas Association have been summarized in May, 1949, as follows:—

"The objective of this project is to develop a means of determining interchangeability of gas mixtures, where the base gas is in the heating-value range of 540 Btu either by—

"1. A mathematical formula which will require only a knowledge of the analysis of the mixture to determine its interchangeability, or

"2. A test burner or series of burners which will indicate the expected performance of any given mixture with customer appliance.

"The first phase of the project was a desk study to determine if it were possible to utilize the formulae previously developed by the Laboratories for the use of gases of 800 Btu or more for peak load supplements where the base load was natural gas.

"It was quickly determined that these formulae did not apply.

"The next phase was a field survey for the purpose of learning the methods used by various operating companies for determination of interchangeability. On the basis of this survey, a method of procedure was developed and necessary equipment assembled.

"The third phase of the investigation consisted of actually substituting various supplemental gas mixtures for each of 5 adjustment gases for which a number of appliances representative of those found to be most critical in the field survey were first adjusted. Some 30 supplemental gases were used in varying proportions with the adjustment gas and the performance of each appliance noted. At the same time each substitute gas mixture was tested in a number of test burners and the performance of pilot valves observed."

Interpretation of Data

"The test work has been completed and the supervising committee has worked with the Laboratories staff in attempting to interpret the data. While it has been impossible, up to the present time, to develop formulae to predict interchangeability and no single test burner has been found which can be used, there is some indication that after careful consideration of all the data some mathematical means of predicting interchangeability may be found and test burner observations may be useful. In the meantime, limiting mixtures of each supplemental gas with the five adjustment gases have been established and the data compiled in handbook form. One report has been distributed and the others will soon be available.

"The data compiled indicates those supplemental mixtures which were found by test to be satisfactory substitutes for each adjustment gas for peak load use.

"This information can be used directly wherever the composition of the adjustment gas is the same as one of the five used, or, if the gases do not differ too widely, the test data can be used as a guide using methods of approximation. A careful study of the bulletins covering this test work is recommended to all concerned with the use of a variety of supplemental gases for meeting peak loads.

"This project has emphasized the need for a study of the fundamentals of combustion. It is quite evident that our present knowledge is insufficient to permit the proper design of burners which will incorporate the flexibility necessary to satisfactorily burn the variety of gaseous mixtures we would like to use during peak load periods. Such a project is now in the formulation stage."

There are several simpler formulae which have been proposed for use in determining the interchangeability of gases.

(44) The Knoy formula is well known—

$$C = \frac{H - 175}{\sqrt{G}}$$

C = a constant
H = heating value of gas, Btu per cubic foot
G = specific gravity of gas (air = 1)
175 = the heating value in Btu per cubic foot of the primary air-gas mixture which is assumed to be the proper adjustment for domestic burners.

The theory of this formula is that gases which have the same "C" factor are interchangeable. Actually the normal flexibility of most domestic-appliance burners allows some variation in the "C" factor. This deviation will not usually exceed 10 per cent up or down from the "C" factor of the adjustment gas. "C" factor for substitute gases which are above that of the adjustment gas indicate softer types of flames, while harder flames are indicated if the "C" factor is found to be below that for the adjustment gas.

New Test Burners Devised

It is stated that the results obtained by the use of the Knoy formula may be misleading if the chemical composition of the substitute gas does not correspond to that of the adjustment gas, and as a rule, limit mixtures defined by means of A G A Index C are somewhat more reliable than those indicated by the Knoy formula.

Many test burners have been devised to assist in evaluating the interchangeability of gases by observation of flame characteristics. At the present time there is no available instrument which can be applied in all cases to evaluate the gas quality. In approaching a problem involving interchangeability of gas, it is desirable to make calculations first, using the interchangeability equations and then burn the prepared mixtures in appliances having burners characteristic of those used in the community to be certain that the substitute gases will actually burn satisfactorily.

It is desirable that gas companies keep a control burner at the inlet and outlet of their gas-storage holders in order that they may, at all times, have a knowledge of the burning characteristics of the gas being produced and sent out.

Having considered the possibilities of using substitute gases for some normal send-out gas, it is apparent that no general statement can be made that any gas will or will not satisfactorily replace another gas. It is necessary that each situation be studied carefully, using the equations given here together with operation of test appliances.

Oil Gas Not Complete Replacement

It can be stated that high Btu oil gas, as now known, cannot be used as complete replacement for natural gas. However, some 30 to 60 per cent of these high Btu oil gases can be used in admixture with natural gas without excessive complaints from the consumers of the gas.

It must be pointed out that in some cases substitute gases appear to be entirely satisfactory from the standpoint of visual flame characteristics, but the products of combustion may contain dangerous quantities of carbon monoxide.

It should be possible to supply an equation based solely on the chemical analysis of the gases which could be used for determining the interchangeability of gases. The Laboratories of the American Gas Association have done considerable work on this problem and may be able to supply such an equation in the near future. In the meantime, it is necessary to use the equations so far developed and consider each case separately.

Storage of Gases or Mixtures of Gases Considering Deviations from Ideal Gas Laws

STORAGE cylinders, operating at relatively high pressures, are capable of offering increased storage capacity, considering the effect of deviation from the ideal gas law, to the extent of approximately 40 per cent over underground storage sands.

In the case of mixtures of gases, such as natural gas, deviation from the ideal gas law is dependent on the composition of the mixture. A method of determining this deviation for a gas of any composition and of calculating the increase in volumetric capacity under optimum operating conditions is presented.

In the compression of a gas, when the working pressure exceeds approximately 50 psi gage, there is a difference between the actual volume and the volume expected as determined by the ideal gas law,

$$PV = NR'T \qquad (1)$$

where

P = pressure in pounds per square inch absolute

V = volume in cubic feet

N = number of pound-moles of gas = $\frac{\text{Weight of gas in pounds}}{\text{molecular weight}}$

R' = universal gas constant = 10.71 for cubic foot and pounds per square inch

T = temperature, absolute = 460 + °F

The difference is generally a shrinkage accompanied by a corresponding increase in density. This shrinkage, or deviation, is a function of both pressure and temperature, and reaches a maximum at the critical pressure and temperature of the gas.

Since the ideal gas law (Equation 1) has been used in the derivation of nearly all equations of state, the most convenient method for determining the pressure, volume, temperature relationships of a gas or gaseous mixture is to introduce into Equation 1 a compressibility factor Z which represents the deviation of the gas in question from the ideal gas laws and may be expressed as follows:

$$PV = ZNR'T \qquad (2)$$

where

Z = compressibility factor

Actually, the compressibility factor Z is a dimensionless correction factor dependent on the character of the gas, the temperature, and the pressure. Values of Z have been experimentally determined[1][2]*, and were found to be a function of reduced pressure and reduced temperature, and have been plotted accordingly in Fig. 1.

The compressibility factor Z, or the deviation of a gas or a gas mixture from the ideal gas laws, is expressed in terms of reduced pressure P_r (ratio of the actual absolute pressure to the critical pressure) and of reduced temperature T_r (ratio of the actual temperature to the critical temperature), the relationship being expressed as follows:

$$P_r = P/P_c \qquad (3)$$

$$T_r = T/T_c \qquad (4)$$

TABLE 1—PROPERTIES OF GASES.

Gas	Formula	Molecular weight	Boiling point at atmosphere °F	Specific gravity Air = 1.00	Critical temperature °F abs.	Critical pressure psi abs.
Methane	CH_4	16.03	−259	0.553	344	673
Ethane	C_2H_6	30.05	−127	1.037	549	712
Propane	C_3H_8	44.06	− 44	1.521	666	632
Isobutane	C_4H_{10}	58.08	10	2.005	732	544
Isopentane	C_5H_{12}	72.09	82	2.488	829	482
Carbon dioxide	CO_2	44.00	−109	1.520	548	1073
Nitrogen	N_2	28.02	−320	0.970	227	492
Oxygen	O_2	32.00	−297	1.105	278	730

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where

P = pressure in pounds per square inch absolute

T = temperature, absolute = 460 + °F

P_c = critical pressure of gas or gas mixture

T_c = critical temperature of gas or gas mixture

The critical pressure of a gas is the pressure under which the gas may exist in a gaseous state in equilibrium with its liquid at the critical temperature. The critical temperature is the temperature above which a gas cannot be liquefied by pressure alone. Values of critical constants may be obtained from critical tables and handbooks, or reference may be made to Table I wherein are listed properties of constituent gases.

In a gaseous mixture consisting of numerous component gases, the compressibility factor is determined by having recourse to the so-called pseudo-critical values of the mixture. The pseudo-critical pressure is the molecular average critical pressure of the gas mixture and the pseudo-critical temperature is the molecular average critical temperature of the mixture. The relationship to the critical pressure and temperature of the fundamental gases may be expressed as follows:

$$P_c = (P_c)_a N_a + (P_c)_b N_b + \qquad (5)$$

$$T_c = (T_c)_a N_a + (T_c)_b N_b + \qquad (6)$$

where

N_a = Gas (a) of gas mixture as a volume fraction

N_b = Gas (b) of gas mixture as a volume fraction

P_c = Pseudo-critical pressure of gas mixture

$(P_c)_a$ = Critical pressure of N_a

$(P_c)_b$ = Critical pressure of N_b

T_c = Pseudo-critical temperature of gas mixture

$(T_c)_a$ = Critical temperature of N_a

$(T_c)_b$ = Critical temperature of N_b

In order to illustrate the determination of the compressibility factor, the following example is cited:

(Continued on next page)

TABLE 2—VARIOUS GAS ANALYSES.

Component	Formula	Example	Natural gas		Coke-oven gas	Producer gas: Pittsburgh coal Best	Producer gas: Pittsburgh coal Average	Producer gas: Illinois coal
Analysis number			1	2	3	4	5	6
Methane	CH_4	84.8	84.5	94.5	29.7	3.4	2.3	2.5
Ethane	C_2H_6	14.3	11.5	0.5	1.1	....	....	....
Carbon monoxide	CO	....	....	....	5.9	27.5	24.7	25.4
Hydrogen	H_2	....	....	....	57.0	12.7	15.0	11.0
Oxygen	O_2	0.2	....	0.3	....	0.2	0.2	0.1
Nitrogen	N_2	0.6	3.8	4.0	0.7	50.8	52.2	54.0
Carbon dioxide	CO_2	0.2	0.2	0.2	0.7	4.6	4.8	5.2
Ethylene	C_2H_4	....	....	0.5	3.4	0.8	0.8	0.6
Critical pressure, psi abs.	P_c	678.1	672.0	667.3	381.6	494.8	486.4	494.8
Critical temperature, °F abs.	T_c	372.6	363.7	341.4	179.5	231.0	226.1	231.1
Reduced temperature	T_r	1.40	1.43	1.52	2.90	2.25	2.30	2.25

TABLE 3—DETERMINATION OF COMPRESSIBILITY FACTOR AND ATMOSPHERIC VOLUMETRIC MULTIPLIER.

Given: Critical Pressure = 678.1 psi abs.
Critical Temperature = 372.6° F abs.
Reduced Temperature = 1.396

Storage pressure P_p	Reduced pressure $P_r = \frac{P_p}{678.1}$	From Fig. 1 Z_p For $T_r = 1.396$ For $P_r = \frac{P_p}{678.1}$	$14.73Z_p$	Atmospheric volumetric multiplier $\frac{P_p}{14.73Z_p}$
100	.147	.983	14.48	6.91
250	.369	.955	14.07	17.77
500	.737	.912	13.43	37.23
750	1.106	.871	12.83	58.46
1000	1.475	.828	12.20	81.97
1250	1.843	.790	11.64	107.39
1500	2.212	.756	11.14	134.65
1750	2.581	.736	10.84	161.44
2000	2.949	.721	10.62	188.32
2250	3.318	.718	10.58	212.67
2500	3.687	.722	10.64	234.96
2750	4.055	.733	10.80	254.63
3000	4.424	.748	11.02	272.23

Example—Gas analysis, per cent by volume: Methane, 84.81; Ethane, 14.26; Nitrogen, 0.63; Carbon Dioxide, 0.15; Oxygen, 0.15. Required, the deviation for 2000 psi absolute and 60° F. The pseudo-critical pressure and temperature must be determined by means of Equations (5) and (6) and Table I.

$$P_c = (P_c)_a N_a + (P_c)_b N_b + \quad (5)$$

$$P_c = 673(0.8481) + 712(0.1426) + 492(0.0063) + 1073(0.0015) + 730(0.0015) = 678.1 \text{ psi absolute}$$

$$T_c = (T_c)_a N_a + (T_c)_b N_b + \quad (6)$$

$$T_c = 344(0.8481) + 549(0.1426) + 227(0.0063) + 548(0.0015) + 278(0.0015) = 372.6° \text{ F absolute}$$

Reduced pressure and reduced temperature are determined from Equations (3) and (4).

$$P_r = P/P_c \quad (3)$$

$$P_r = \frac{2000}{678.1} = 2.949$$

$$T_r = T/T_c \quad (4)$$

$$T_r = \frac{60 + 460}{372.6} = 1.396$$

From Fig. 1, for $T_r = 1.396$ and $P_r = 2.949$, we find the compressibility factor $Z = 0.722$. It should be noted that if in the preceding example the gas had been at atmospheric pressure, the compressibility factor would approximate unity.

For comparative purposes Fig. 2 has been prepared based on the seven gas analyses of Table II giving the compressibility factor Z as a function of storage pressure and reduced temperature. Similarly, for any other gas analyses plots could be made to indicate the optimum pressure-deviation relationship. In this manner the designer of storage cylinders will be able to determine the magnitude of the increase in the storage capacity under optimum conditions. In the case of gas analysis No. 1, the best operating pressure would be 2250 psi absolute, the compressibility factor being .740.

If under standard conditions of pressure and temperature the volumetric content of a cylinder is known, the magnitude of the increase in storage capacity may be predicted based on the deviation from the ideal gas laws and the storage pressure.

$P_a V_a = Z_a NR'T$ and $P_p V_p = Z_p NR'T$ where subscripts a and p represent values at standard or atmospheric conditions and under pressure, then

$$V_a = \frac{Z_a P_p}{Z_p P_a} V_p \quad (7)$$

but Z_a = unity at standard conditions and $P_a = 14.73$ psi. When substituted in Equation (7) the expression in terms of standard volume will be

$$V_a = \frac{P_p}{14.73 Z_p} V_p \quad (8)$$

Therefore, the expression $\frac{P_p}{14.73Z_p}$ represents a volumetric multiplier and, knowing the volume under standard conditions, the volume of gas that can be stored under operating conditions may be anticipated by multiplying the known volume by this calculated value.

Atmospheric volumetric multipliers for the seven gas analyses of Table II have been determined and are shown in Fig. 3, and, similarly, for any other gas analysis a plot may be established to show the expected volumetric increase for each analysis.

To further illustrate, using the gas analysis of the previous example, Table III shows the required calculations for the determination of the compressibility factor Z and the volumetric multiplier k for a storage pressure range of 100 psi to 3000 psi absolute.

In the foregoing discussion the probabilities of hydrate formation or liquefaction of the gas have not been taken into consideration. For any specific gas mixture these critical points should be determined for the anticipated operation conditions before proceeding with the investigation of optimum conditions of storage.

Figures 1, 2 and 3, charts relating to this discussion are on the three pages following.

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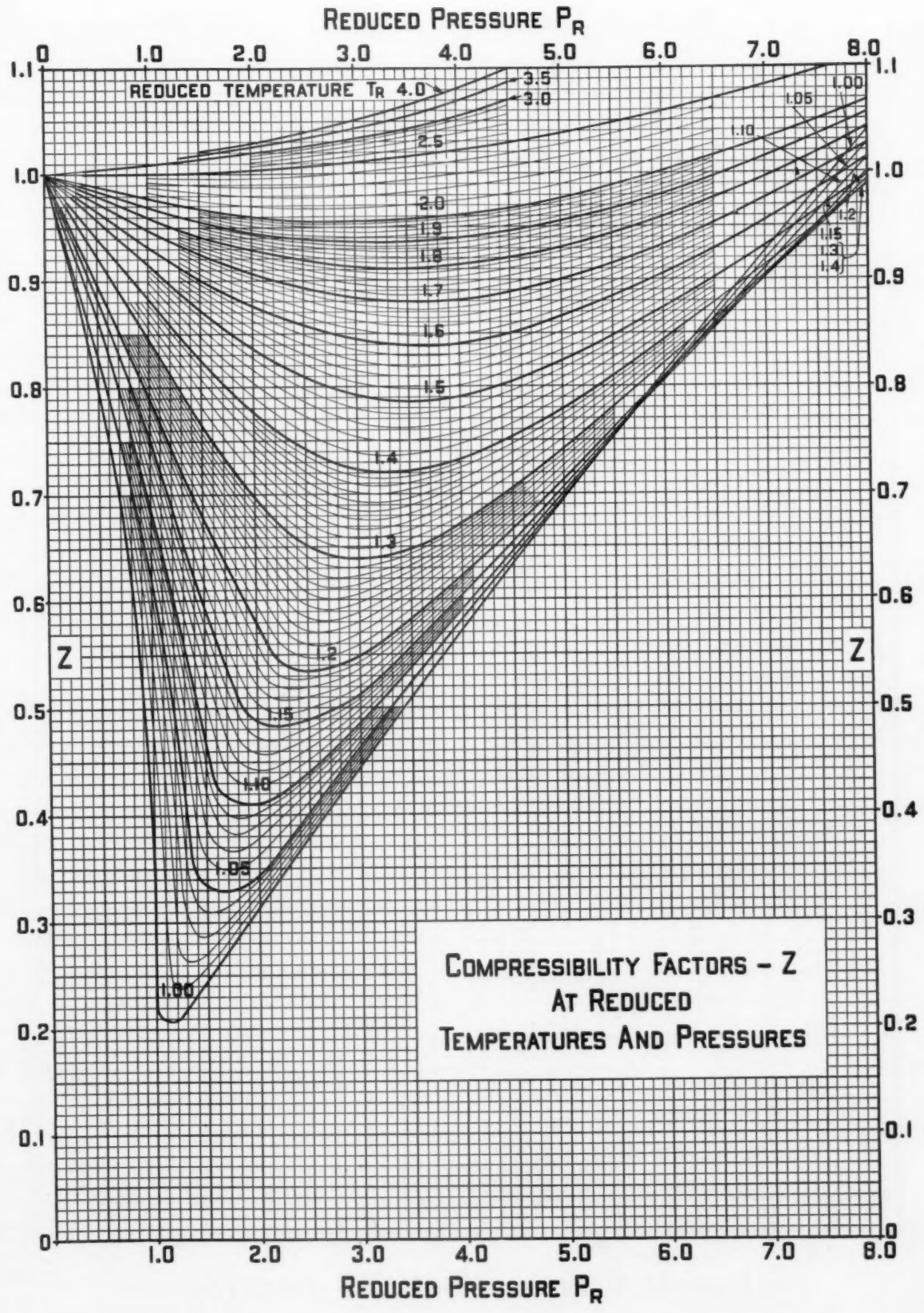

Fig. 1

By permission, from "Natural Gasoline and the Volatile Hydrocarbons," by Brown, Katz, Oberfell and Alden.

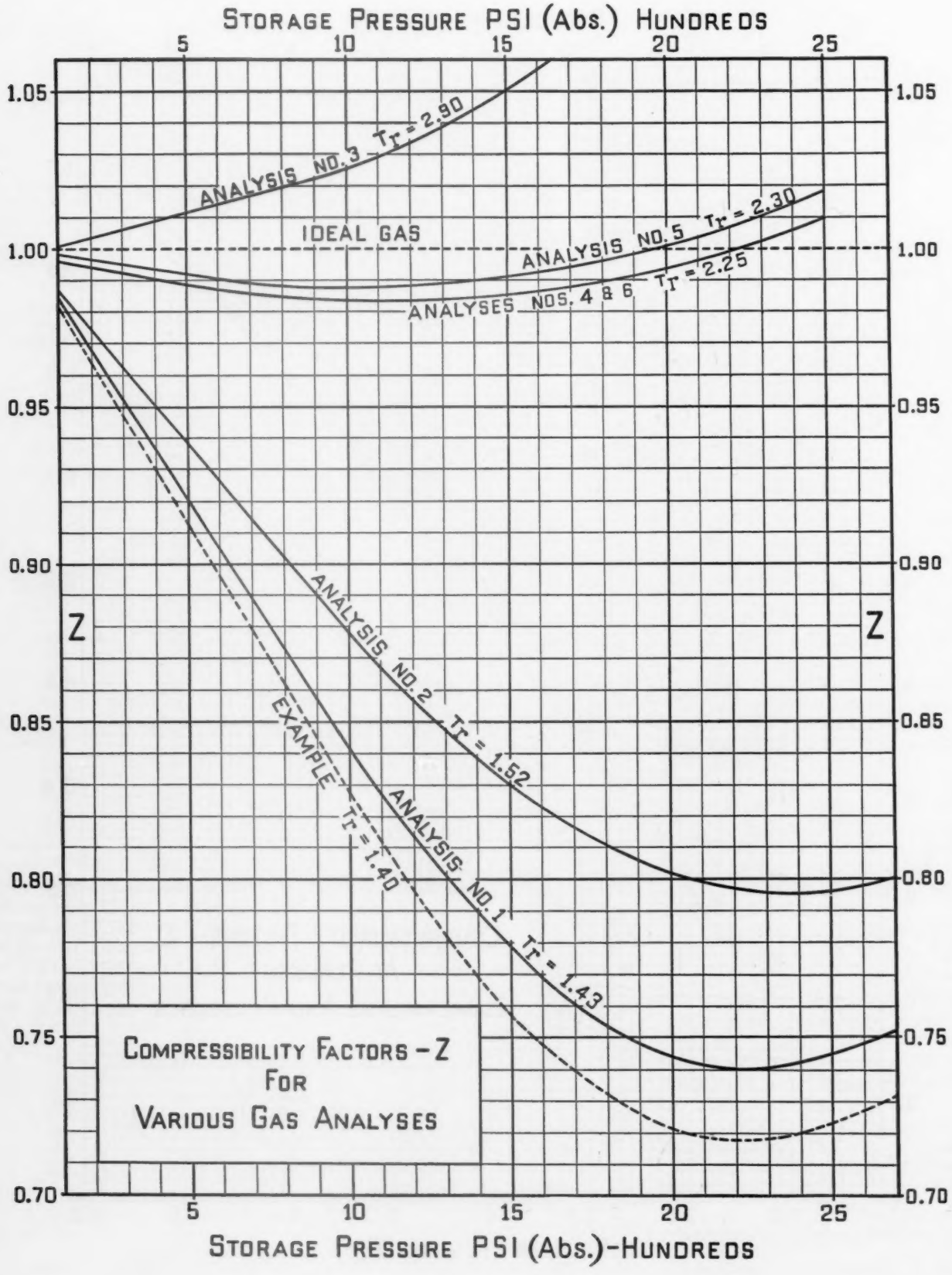
STORAGE PRESSURE PSI (Abs.) HUNDREDS
5
10
15
20
25
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
Z
ANALYSIS NO. 3 Tr = 2.90
IDEAL GAS
ANALYSIS NO. 5 Tr = 2.30
ANALYSES NOS. 4 & 6 Tr = 2.25
ANALYSIS NO. 2 Tr = 1.52
EXAMPLE Tr = 1.40
ANALYSIS NO. 1 Tr = 1.43
COMPRESSIBILITY FACTORS - Z
FOR
VARIOUS GAS ANALYSES
STORAGE PRESSURE PSI (Abs.)-HUNDREDS

Fig. 2

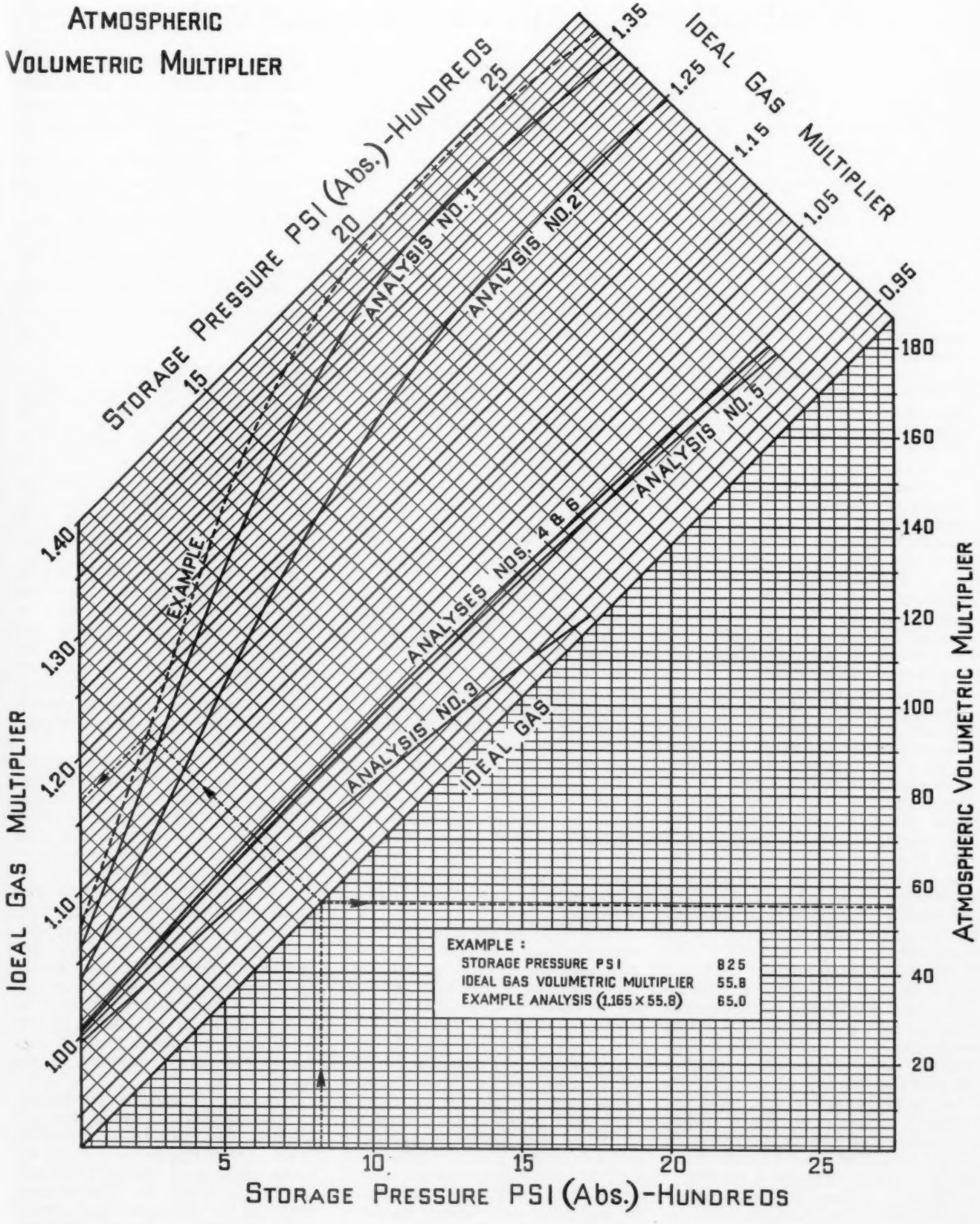
ATMOSPHERIC
VOLUMETRIC MULTIPLIER
STORAGE PRESSURE PSI (Abs.)-HUNDREDS
IDEAL GAS MULTIPLIER
ATMOSPHERIC VOLUMETRIC MULTIPLIER
ANALYSIS NO. 1
ANALYSIS NO. 2
ANALYSIS NO. 5
ANALYSES NOS. 4 & 6
ANALYSIS NO. 3
IDEAL GAS
EXAMPLE
EXAMPLE :
STORAGE PRESSURE PSI 825
IDEAL GAS VOLUMETRIC MULTIPLIER 55.8
EXAMPLE ANALYSIS (1.165 × 55.8) 65.0

Fig. 3

Methods of Controlling Corrosion

THE control of corrosion can be accomplished by one or more of several general methods such as: selection of right-of-way to avoid obvious corrosive spots; coating the pipe with some kind of protective film or wrapper; or by forcing current to flow onto the pipe either through its entire length or at least within those areas at which current would otherwise be flowing off of the pipe due to the presence of natural galvanic cells or to the pipe being within the positive area of stray earth currents. This latter means of protection can be accomplished in two general ways, that is, by creating a galvanic cell directly opposed to the natural galvanic cell of the pipe line, or by impressing electric current from an outside source directly on the pipe line.

Ordinarily the right-of-way for a line is chosen to approximate a straight line between two points and at the same time permit ease of construction and maintenance of the pipe line. A soil survey conducted along the proposed course of a pipe line sometimes indicates small corrosive areas which can be avoided without increasing either the installation cost of the line or its accessibility for maintenance. This, of course, is the first step in the control of corrosion.

The second general method for preventing corrosion is to completely cover the surface of the buried pipe with some kind of a protective coating.

All of the three general types of corrosion involve a flow of electric current. The extent of the corrosion depends upon the magnitude of these electric currents. It becomes obvious therefore that if we can maintain some type of electric insulating material as a barrier between the pipe and ground it would be possible to stop the flow of these electrical currents and thereby prevent the corrosion.

There are many different kinds and types of coating materials, such as asphalt, coal tars, plastics, mastics, greases and concrete, and although it is not an insulating material, the metallic coating, such as galvanizing. A coating which is perfectly satisfactory on one pipe line for one location may or may not be satisfactory on another pipe line at a different location because the soil conditions and environment at one location are entirely different from those at another.

Metallic coatings (galvanized pipe) are not well adapted to underground use because of the galvanic action between the metallic coating and the dissimilar nearby metals. These metallic coatings are often used to considerable advantage to prevent atmospheric corrosion.

THIS ARTICLE on corrosion control and the one on cathodic protection, next page, have been adapted, with permission, from "A Manual on Underground Corrosion," a copyrighted book prepared by the Columbia Gas System Service Corporation, a subsidiary of Columbia Gas System.

Concrete coatings were at one time very popular and extensively used to combat corrosion. Their cost is relatively high, and since they have a tendency to absorb moisture, check and crack, they are not now extensively used. There are actual instances of locations where the use of concrete coatings has accelerated pipe corrosion.

The grease coatings are made from a petroleum base with a paraffin or waxlike texture, and may be applied either hot or cold depending upon the specification of the particular grease coating. Both the hot and cold greases must be shielded from the surrounding earth by a wrapper, since the soil backfill tends to damage the grease coating. In addition to this displacement of coating, the soil tends to absorb some of the materials in this type of coating.

Most mastics are considered to be good coatings. These coatings are composed of aggregates such as sand, gravel, asbestos, or clay, bonded with either coal tar, asphalt, or one of the newer plastics. They may be either hot or cold applications depending upon the specification of the material used. They are generally applied as a thick coating, sometimes as much as ⅜ to ¾ of an inch in thickness. These mastic coatings are relatively expensive and consequently are not often used except for highly corrosive soil conditions.

Plastic coatings are among the newcomers in pipe line protective coating materials. Most of them are still in the early stages of development and have not yet been tested by actual industrial application. Preliminary tests indicate that some of these may be highly desirable pipe protective materials. But definite statements concerning their relative qualifications are not now possible.

The coal tar and asphalt coatings are by far the most popular of the coating materials used to prevent corrosion. Of these two bituminous coatings, asphalt and coal tar, asphalt as a basic material for protection ranks among the oldest known to man. The Egyptians made extensive use of asphalt as a water proofing and protective material in the construction of their boats. Natural asphalt was also used as a protection against water in the construction of tombs and mummy cases. Down through the ages, constant references are made to natural asphalt as a protective coating.

Asphalt base coating materials whether from a natural source or as a petroleum refining residue are extensively used today as pipe coating material. In general, they are less susceptible to impact and temperature changes than the coal tar base enamels, but they may be affected by the absorption of small quantities of soil moisture or they may be dissolved by oil products contained in the soil.

Coal tar base coatings are probably the most widely used pipe line coating materials of the present day. This is because they can be combined in many different ways to meet the many different requirements of pipe line construction. Their permanence, continuity, hardness, adhesion and corrosion resistance, combined with their relatively low cost, make them more desirable as a pipe line protective coating material.

Both coal tar base coatings and asphalt base coatings are manufactured to meet different specifications such as softening point, weight per gallon, coefficient of expansion, etc., so that the most appropriate protection can be selected for any particular job of coating. They are generally applied to provide approximately 3/32 of an inch of coating thickness.

One of the most important steps for the application of either of these coatings is the proper preparation of the pipe to be coated. The pipe must be clean, free of dirt, moisture, rust, mill scale and the like, and must be primed by painting with some material which will bond to the pipe and to the material with which it is proposed to protect the pipe. In most cases, with hot coatings at least, it is customary to wrap over the enamel or coating while it is still hot and viscous with a felt, asbestos, or glass fiber wrapper. The purpose of the wrapper is to prevent injury to the coating during backfill and deformation of the coating due to soil stresses produced as the backfill settles.

Sometimes combinations of wrappers are used. An excellent combination consisting of a fiber glass wrapper imbedded in the enamel supplemented by an asbestos felt wrapper bonded to the surface of the enamel. The glass wrapper reinforces the coating and the asbestos felt wrapper protects it from soil stress.

Sometimes these coatings are applied by hand and sometimes by the use of the machinery. Small coating jobs including the patching of large machine applied

jobs are usually accomplished by hand using a canvas sling and pouring bucket to apply the coating material. Coating jobs which are not large enough to warrant the use of over-the-ditch machinery may be completed by using a rolling rig either along the right-of-way or in the pipe yard or rail terminal.

Inspectors usually watch the application of the coating and wrapper to see that they are applied according to the specifications. In addition to this visual inspection of the application of the coating, most applied coatings are checked to determine whether or not there are any small faults or pinholes commonly called "holidays" in the coating. This is usually accomplished by using one of several different kinds of electrical testing devices or "holiday" detectors.

All of these tests are done before the pipe is lowered in the ditch. During the course of lowering and backfilling, additional holidays may be formed. These can be detected by means of a special electrical device even though the pipe is buried. If this special instrument indicates any large areas where the coating has been damaged, it may be necessary to uncover the line to repair the damaged place. If the instrument indicates that the area is very small, then other means of protection may be utilized.

Cathodic Protection

ALTHOUGH this method of protection is rather simple in principle, its application can become complicated, particularly if there are other underground structures in the same area. The actual method of distributing the "impressed current" along the pipe line can be accomplished by many different methods. Typical wiring diagrams for some of these methods are shown in Figures 1, 2 and 3.

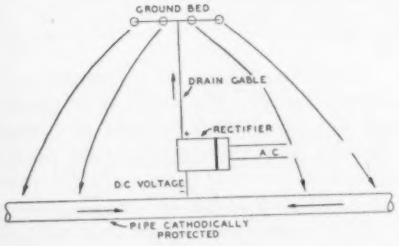

Figure 1. Cathodic Protection: Single Rectifier and Ground Bed (Anode).

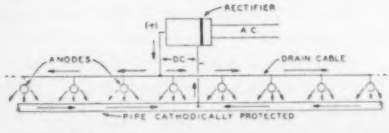

Figure 2. Cathodic Protection: Rectifier and Distributed Ground Bed or Anodes.

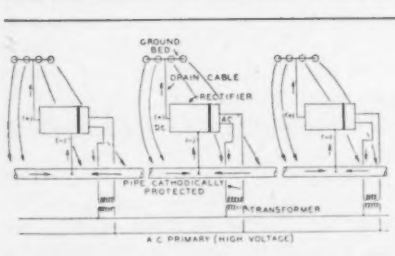

Figure 3. Cathodic Protection: Distributed Rectifiers with Single Ground Beds.

This system of protection is also susceptible to complications because of what is called "cathodic interference" (Figure 4). Suppose, for example, there is a high pressure line going through that portion of a distribution system which it is desired to protect by means of "impressed current." This high pressure line may also pick up current from the ground and carry it along to some place where the high pressure line crosses over or goes near the distribution line. Then because the current has to get back to the power source, it will jump from the high pressure line to the ground to the distribution line. This short section of the high pressure line becomes an anode.

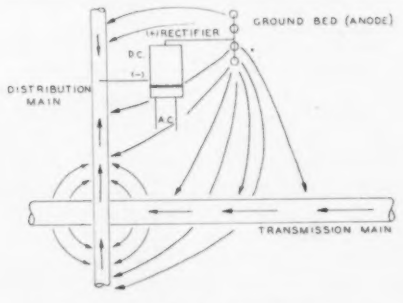

Fig. 4. Cathodic Interference.

Every ampere of current leaving the pipe in this area is going to carry pipe wall metal with it, 20 pounds per ampere per year, and a leak on the high pressure line could be guaranteed.

The same sort of cathodic interference may be caused by reason of some other company installing "impressed current" protection for their system of cables or pipe lines as illustrated in Figure 5. In this case, the rails of an abandoned street car system are being used as the ground bed is collected by the other underground structures (Pipeline A and Pipeline B). The stray currents that have collected on these pipe lines must return to the cathodic protection unit, therefore, there will of necessity be an area somewhere along these pipe lines where this current is flowing from the pipe line to the ground. In other words, the lines have become anodes, and it is the anode which corrodes.

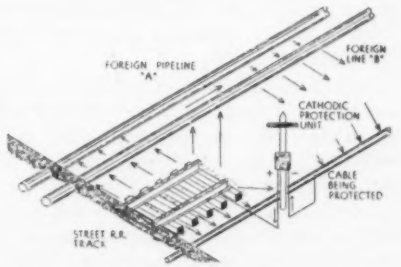

Figure 5. Stray Current Corrosion.

It sometimes requires a very elaborate wiring system to effectively equalize the various underground structures which may be exposed to stray currents by the use of cathodic protection units. In practice, the use of "impressed current" to protect a network of lines becomes so complicated that its application should only be undertaken by the experienced Electrolysis and Corrosion Engineer.

We have proved by experience that a copper service line can be protected by reason of its being the cathode of a dissimilar metal galvanic cell. It follows quite logically that if it were possible to make all of the area along a pipe line the cathode of a strong galvanic cell by using an expendable dissimilar metal, it would be possible to suppress the natural anode areas along the pipe, and thus keep them from developing pit holes. There are three readily available metals, aluminum, zinc, and magnesium, each of which will form reasonably strong galvanic cells when combined with iron. Any one of the three can be used to construct this galvanic cell. Magnesium forms the strongest cell of the three and is therefore most often used (Figure 6).

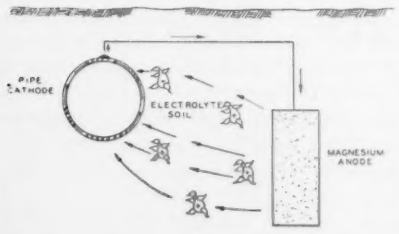

Figure 6. Cathodic Protection: Galvanic Anodes.

This expendable anode galvanic cell as used for pipe protection is similar to a flashlight battery. The magnesium ingot is the expendable anode; the soil is the electrolyte; the pipe surface the center cathode; and the insulated wire, with one end soldered to the pipe and the other to the magnesium, completes the electrical circuit. Current will flow from the magnesium to the ground, taking metal ions of magnesium with it. It then flows through the ground onto the pipe, counteracting the undesirable natural galvanic cells that may be encountered back to the magnesium anode through the connecting wire.

The ingots of magnesium used to create these galvanic cells may be any one of a number of different sizes and weights. The sizes ordinarily used are 4#, 8#, 12#, 16#, and 32#. Their physical dimensions are varied, depending upon who manufactured the ingots. Some of these ingots are cylinders from 4" to 8" in diameter. Others are square in cross section and are from 2" to 6" on a side.

Still another type of magnesium anode is in the form of a ribbon about ⅜" x ¾" with a solid iron wire as a core. This ribbon can be obtained in 2,000' spools and weighs about a quarter of a pound per foot.

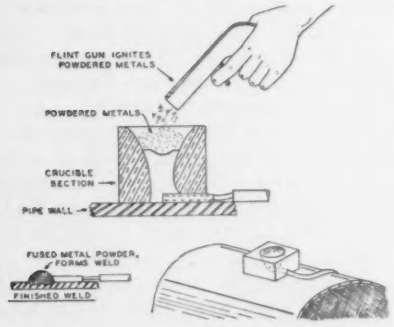

Figure 7. Thermit Weld Process.

Except for the ribbon type anodes, the magnesium is usually installed by digging a hole deep enough to put the ingot of magnesium about on a level with the pipe line, filling in around the magnesium with some sort of special "backfill." The purpose of the "backfill" is to provide better electrical efficiency for the magnesium. There are many specially prepared backfills for this purpose, but field tests have demonstrated that ordinary builders plaster mixed with sand is just as satisfactory as the most expensive special backfill. An insulated copper wire is used to connect the iron core of the magnesium anode to the surface of the pipe. Connections to the pipe are ordinarily made by using a thermit welding cup to fuse the wire to the pipe metal (Figure 7). This welded joint must then be covered with an insulating material such as pipe coating to keep it from creating an additional and undesirable galvanic cell.

There are many possible combinations for connecting anodes to the pipe line. The size of anode, the number, their distance apart, the distance from the pipe line, and the like, are all functions of the use to be made of the anode. A number of anodes spaced from 5 to 50' apart along the right-of-way may be attached to a single wire running parallel to the pipe line. This wire in turn will be connected to the pipe line at about 500' intervals. In other cases individual anodes are directly connected by wire to the pipe line and these anodes will be whatever distance apart required to insure that some current, small amount though it may be, is flowing onto every square foot of the pipe line it is proposed to protect.

Figures 8 and 9 show typical installations of these combinations.

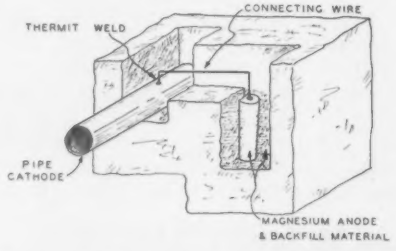

Figure 8. Cathodic Protection: Single Anode Installation.

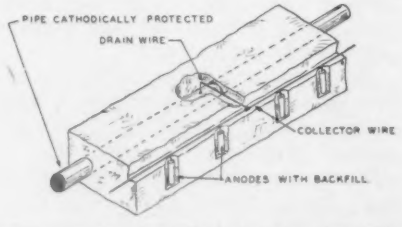

Figure 9. Cathodic Protection: Multiple Anodes in Series Installation.

When the ribbon type magnesium anode is used, it is plowed under the surface of the ground and runs parallel to the pipe line. The pipe and ribbon are connected by insulated wire at intervals along the length of the installation. This continuous ribbon type anode is plowed in by using a conventional cable laying plow (Figure 10).

The number of locations at which it is possible to use this continuous ribbon is limited by the fact that ⅜" x ¾" ribbon weighing about a quarter of a pound per foot does not provide a very large mass of magnesium at any one place along the pipe line. Therefore, it cannot be used where relatively large amounts of current will flow onto the line. For the most part, installations of ribbon may be used in soils having a relatively high resistance to the flow of electricity, for ordinary installations on small diameter pipe, or where it is only desired to protect the line for a short period, say five to ten years.

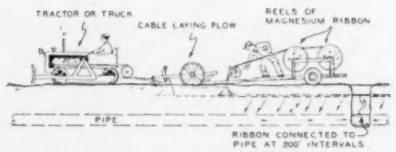

Figure 10. Cathodic Protection: Magnesium Ribbon Installation.

Most installations of magnesium are designed so that the magnesium anodes will provide a small amount of current flowing onto each square foot of the pipe line and still have sufficient mass of magnesium to last at least 25 years.

The magnesium anode will corrode to provide this protection, and enough must be installed so that the amount of magnesium present is sufficient to provide metal to corrode for the period over which it is proposed to protect the pipe line.

The type of anode installation to be made is a matter of choice to the corrosion engineer. The installation he selects will depend upon a number of factors such as the size of the pipe line, the number and activity of the galvanic cells existing along the pipe line, whether or not the soil offers very much resistance to the flow of electricity, and of course, how many years of life it is desired to add to the unprotected normal life of the line.

When magnesium anodes are installed in connection with the regular maintenance and repair program of the pipe line, there is no necessity for having a "profile" or other special tests. Any time it becomes necessary to replace a short piece of line, two or three anodes or one anode for each 20' joint can be installed at the same time in the same ditch with the pipe (Figure 11).

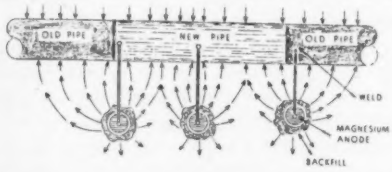

Figure 11. Cathodic Protection: Magnesium Anodes to Protect Old and New Pipeline.

Once the field crews have been shown how to make the installation, they can continue by themselves. There is no need for a corrosion engineer to be on hand for each individual job.

If some particular spot along the pipe line is developing pit hole leaks, then a single 8″ magnesium anode can be installed at the time the pit hole saddle is attached (Figure 12). Once again, the field crews repairing the leak can make the installation of the anode.

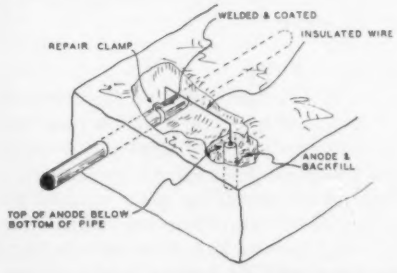

Figure 12. Cathodic Protection: Single Anode Installation in Leak Repair Bell Hole.

With expendable anode installations the deliberate use of an insulated joint may become a very desirable feature. By properly isolating various sections of the line, one from the other, it is often possible to protect the line against corrosion without affecting other sections not requiring protection, and perhaps even make it possible to use fewer anodes to secure the desired protection. This is particularly true on distribution systems. Figures 13 and 14 show typical installations of magnesium anodes on distribution mains and services that are electrically insulated from other structures.

Expendable magnesium anodes can be extremely valuable to prevent the corrosion of coated pipe on both transmission and distribution piping but particularly on distribution systems. Figure 15 shows the cross section at a pipe wall of an insulated line having two small defects in the coating, called "holidays." Any galvanic currents flowing in the pipe line will be concentrated at these places where there is no barrier to the flow of the current from the pipe to the ground, with the result that extreme and rapid pitting may occur. By installing a magnesium anode and connecting it to the coated pipe (Figure 16), it is possible to prevent the flow of current from the pipe to soil at these holidays, and instead, force current to flow from the magnesium anode to the ground, through the hole in the coating onto the pipe line, returning to the magnesium anode through the insulated wire. The magnesium anode will corrode instead of the pipe.

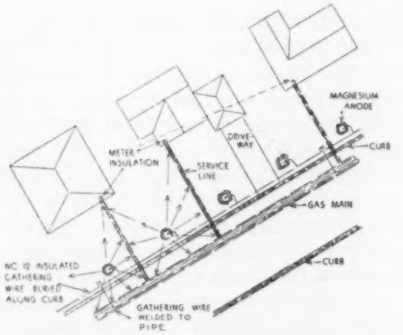

Figure 13. Cathodic Protection: Anode Installation on Distribution Piping.

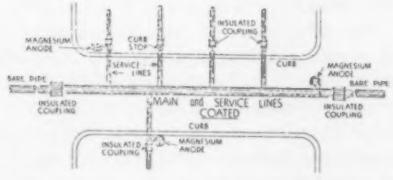

Figure 14. Cathodic Protection: Anode Installation on Coated Distribution Systems of Gas Pipeline.

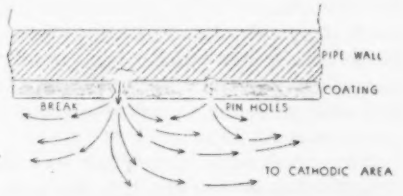

Figure 15. Concentration of Corrosion at Breaks and Pin Holes in Coating.

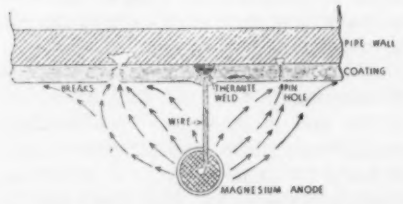

Figure 16. Pipe Protection with Coating and Anodes.

Measurement of pH in Soils and Water

IT is important to understand what the term "pH" actually means. Briefly, pH is a measure of the acidity or alkalinity of a solution.

pH does measure the *strength* of an acid; it does not necessarily measure the amount of the acid. Weak acids such as acetic can be added in moderate amounts to a solution without radically affecting the acidity. Similar amounts of strong acids like sulfuric, when added to the same solution, will cause a large change in acidity. Strength or weakness of an acid depends upon the extent of dissociation, or ionization, of the acid to give hydrogen ions. The greater the ionization of the acid, the more the hydrogen ion activity and the greater the acidity of the solution.

The pH scale is a convenient logarithmic expression of the hydrogen ion concentration in terms of a normal solution. On this scale, 7 is neutral, while lower numbers indicate greater acidity and higher numbers, less acidity (greater alkalinity). For practical purposes the pH scale is considered as encompassing the ranges 0 to 14, since solutions with pH values above or below this range are rarely encountered. On the pH scale, a solution of pH 4 is ten times as acid as one of pH 5 and one-hundred times as acid as a solution of pH 6. A small error in pH value can mean a large error in acid activity. A pH of 7 is neutral or neither acid nor alkaline.

The two general methods for determining pH are the *colorimetric* and *electrometric* methods. The two operate on entirely different principles and have corresponding differences in utility and accuracy.

Careful consideration of each application is advisable before deciding upon a particular method of pH measurement. Equal consideration should also be given to future applications since the equipment for a given application may be of little value should requirements undergo a change.

Colorimetric pH measurements

The colorimetric method for pH determination utilizes certain organic substances, called "indicators," which change color with change in pH. The simplest color pH test is by means of papers impregnated with indicator dye. These papers are subject to a number of errors, some of which are discussed below. Under favorable conditions, and in experienced hands, "long-range" indicating papers may give an accuracy of about one-half pH, and "short-range" papers, one-quarter pH. In general, however, results with papers should be considered only approximations of actual hydrogen-ion concentration since important errors can occur under some conditions.

Colorimetric pH measurements made by adding solutions of individual indicators to the sample are based on the assumption that when equal quantities of an indicator are added to equal quantities of solutions which have the same pH value, identical colors will be produced. While this is not strictly true, colorimetric pH determinations are useful, providing proper care is taken in making each measurement.

If the colorimetric method is used with samples of unknown pH, it is advisable first to make an approximate determination so that the proper indicator can be selected. Each indicator has a range of about 1.5 pH, and, by using a variety of indicator sets, most of the pH range can be covered.

It is essential in making colorimetric measurements that the test tubes, pipettes, and other vessels used be kept scrupulously clean, and glassware, samples and indicator solutions be protected from fumes and dust. Care must also be taken to protect the colored "standards," such as paper, celluloid, glass, or liquid, against fading. Comparison of sample color against standards must be made under ordinary daylight. If this is not possible, special accessory illumination equipment should be employed to simulate daylight conditions since ordinary artificial light is not satisfactory.

Some limitations of the colorimetric method are apparent. The method depends upon acuteness of vision; cannot be adapted to continuous pH measurement or automatic pH control; requires a number of chemicals, racks and special glassware; is not useable in enclosed systems such as pipe lines. Additional difficulties are encountered especially in field measurements, notably that the colorimetric method is inapplicable to colored or turbid samples, often encountered in corrosion measurements.

It is also important to understand some of the method's less obvious limitations. It has been found that the addition of the indicator, actually a weak acid or weak base, changes the pH of the solution under test. In the case of slightly buffered or unbuffered solutions, this error can be a good fraction of a pH unit or more. Temperature errors are also encountered —phenolphthalein, for example, introduces an error of 0.15 pH per 10°C change. Other errors arise from specific adsorption effects in colloidal suspensions, from salt effects, dilution, dichromatism, hydrolysis, chlorination, etc.

In some cases, special equipment or techniques can be employed in an effort to eliminate or correct for these errors. Generally, however, complications occur and, especially where accuracy is a consideration, the electrometric method should be employed.

Electrometric pH measurements

The electrometric method takes advantage of the fact that, with two electrodes in the solution, a voltage is developed at the electrode which is directly related to the pH. By amplifying and measuring this voltage, the pH of the solution can be read directly from a suitable meter scale. Modern pH meters employing the glass electrode operate in precisely this fashion.

Among the advantages of the electrometric method are greater versatility, accuracy and convenience of use. Measurements can be made under virtually all conditions of temperature, pressure, and composition of solution in the field as well as in the laboratory.

The two principal units required for electrometric determinations are the pH meter and an electrode pair. The electrode pair consists of a reference electrode, usually a calomel type, and a pH-sensitive electrode which can be one of several types.

One such type is the hydrogen electrode on which the pH scale is based. The hydrogen electrode, however, is not considered practical, since the use of hydrogen gas is inconvenient and the electrode is readily poisoned by many substances. Another pH-sensitive type is the quinhydrone electrode which, under favorable conditions, works rather well in the acid region. A third type is the antimony electrode which undergoes a change in potential more or less related to change in pH. All three types have at least one basic fault: in the presence of oxidizing or reducing substances in the sample, reactions occur at the electrodes which give rise to misleading results. The one electrode which is ideally suited for pH measurements is the glass electrode.

The performance of the glass electrode depends largely upon the type of glass from which the pH-sensitive immersion tip is made. In the past, most electrodes used thin bulbs of sodalime glass. A recently developed electrode uses general purpose glass, and the manufacturer claims it is superior because of its greater versatility. This new glass enables a single electrode to cover the temperature range from freezing to boiling as well as almost the entire pH range. The glass tip is so rugged that it can withstand considerable abrasion and even accidental impact against hard objects. Of special interest for field use is the ability of this general purpose glass electrode to measure the pH of soil or surfaces which have only a trace of moisture. There is virtually no danger of breakage even if the electrode is thrust into the soil.

With ordinary electrode glasses, and to a lesser extent with general purpose glass, deviations from the actual pH occur in high pH solutions containing high concentrations of sodium ions. Sodium-ion errors can either be compensated for by adding corrections obtained from a chart, or eliminated by using glass electrodes made from either amber glass or type "E" glass. Amber glass is recommended by one manufacturer for high-temperature measurements at any pH, even in boiling solutions of high acidity or alkalinity.

The pH meter

pH Meters are available for every set of requirements. For portable field use, instruments are available which carry the necessary items for pH measurement within its case. These are simple to operate and withstand even rough handling. For the laboratory, battery-operated and a-c operated pH meters are available. Continuous fully-automatic pH recording and control of process solutions in pipelines, vats and tanks is made possible by the large, line-operated pH indicators.

Actual operation of some makes of pH instruments has been considerably simplified. With the electrodes in the sample, all that is necessary to make a measurement in a series is to move a knob or push button, and the pH reading appears directly on a dial or meter. With these modern instruments, standardization requires only a single buffer check. Temperature compensation is generally built into the meter, and no calculations are required. One manufacturer supplies an internally-shielded glass electrode with a continuous, shielded cable and has eliminated the otherwise-serious effects of electrostatic interference, so that accurate measurements can be made even in the presence of powerful electrical machinery. Maintenance consists merely of occasional addition of saturated KC1 solution to the reference electrode; newly designed glass electrodes are entirely factory-sealed.

Adapted from
Reference Book on Instruments
Issued by
American Gas Association

Nipple-and-Can Test of Soil Corrosivity

IN the nipple-and-can method, the soil corrosivity is determined by the loss in weight of a steel nipple that is immersed in the nearly water-saturated soil and subjected to electrolysis under a potential of two volts for 24 hours.

The nipples used are 4″ unthreaded lengths of ½″ stock black pipe which are cleaned by sandblasting, and identified by letters or numbers stamped near one end. Used nipples may be sandblasted and used again. All foreign material such as rust, paint, grease or dirt is removed with a wire brush or a suitable solvent, such as benzene or carbon tetrachloride. After sandblasting the nipples are wire-brushed to remove any particles of sand adhering to them. The nipples are then weighed, the weight being determined in *grams to the first decimal.*

The soil sample is crushed with mortar and pestle, if necessary, and all extraneous matter, such as plant roots, leaves, wood, paper and asphalt, is removed. Samples containing excess water are air dried. Do not drain off any excess water.

A one-pint friction top can, 4″ deep by 3¼″ diameter, with cover and top rim removed is used as a container, and also serves as the cathode of the test cell. It may be used over and over until it corrodes through, as long as it is thoroughly scrubbed with a brush and hot water between each test.

The test cell is assembled by inserting a No. 1 rubber stopper in the unidentified end of a nipple leaving ½″ protruding, and placing this assembly in the center of the can with the stoppered end down, the stopper serving as an insulator. A cork stopper is placed in the upper end of the nipple to prevent any soil getting inside the nipple. Soil and distilled water in the correct proportions to bring the soil slightly below the saturation point are placed in the can around the nipple, filling the can nearly to the top. More water may be added later if the soil dries out, as it is important that the soil remain at least 50% saturated throughout the test. Soils that do not readily absorb water may be mixed before placing in the can.

The cork stopper is removed from the nipple, and the nipple is connected to the positive terminal of a two-volt storage battery, making it the anode. The negative terminal of the battery is connected to the can. After a period of 24 hours the battery is disconnected, the nipple is removed and immediately washed in warm tap water, steel wool being used to remove the soil and heavier corrosion products if necessary, and then placed in a boiling 2% solution of ammonium citrate until thoroughly clean. The nipple is then washed with boiling water, air dried, and weighed. The loss in weight is reported as the nipple-and-can corrosion index.

Where a large number of tests are to be made it is convenient to assemble a number of cans, such as twelve, in a wooden rack, the cans being soldered to copper or brass strips mounted on removable shelves, the strips being connected to the negative terminal of the battery. Wires are mounted on the under side of the shelves, to which are connected flexible wires terminating in battery clips, which may be fastened to the nipples. These wires are connected to the positive terminal of the battery through a time switch, which may be set for the required 24-hour period. This allows tests to be run over the weekend, and eliminate the human element in timing the test. No appreciable error is introduced by allowing the nipples to remain in the soil for a day after the current is shut off.

Classification of soils

The following classification has been arbitrarily chosen as satisfactory.

Corrosion index	*Type of soil*	*Soil map color code*
0.0 to 0.5	A—Good	Green
0.5 to 0.75	B—Fair	Yellow
0.75 to 1.5	C—Bad	Brown
1.5 and over	D—Very bad	Red

This method has been used extensively and appears to be satisfactory for the types of soils occurring in California and other areas where the soils are alkaline. There are few checks on the reliability of the method when applied to the acid soils of the East. Some of the advantages of the test are ease of manipulation, speed (many tests may be run at the same time), and the extensive correlation that has been obtained with field experience. Some of the objections to the test are that the applied voltage is greater than that occurring in soil corrosion, and that the loss of weight is caused by and is proportional to the current flowing. The current is determined by both the soil resistance and polarization. However, it has been shown that similar data are obtained when six volts is used, and the decrease in current due to polarization seems to be a characteristic of the particular soil.

Adapted from
Reference Book on Instruments
Issued by
American Gas Association

Design and Operation of Baltimore Oil Foggers

by O. W. Lusby
Consolidated Gas Electric Light and Power Company of Baltimore

THE new type of hot oil fogger developed for operations at Baltimore embodies the principles of heating the sweep gas rather than supplying direct heat to the oil; continuously contacting the hot gas with fresh oil, and continuously removing the residue of unvaporized oil from contact with the gas stream. The fogging rate is positively controlled through the rate at which oil is added to the gas by a controlled-volume pump.

Two years of trouble-free operation have demonstrated the advantages of this type of fogging equipment. The fog produced has excellent stability, and has been found widely distributed throughout the system.

A means of clearly establishing the presence of oil fog in the gas has been developed.

Approximately six weeks prior to the introduction of natural gas, we started oil fogging operations in an effort to assure an oil wet distribution system before conversion. When natural gas was temporarily introduced into the system at other points to facilitate conversion, small oil foggers were placed in operation at these locations to oil wet any dust present so as to prevent its movement.

In considering the conditioning of natural gas prior to conversion, it was decided to try to condition the mains so that they would continue to function the same with natural gas as when manufactured gas was distributed. This involved both humidifying and adding oil to the natural gas. In this way it was hoped that the leakage and dust troubles encountered by others after conversion to natural gas would at least be minimized.

An additional reason for the application of oil fog was to coat with oil the rust in the mains and thus reduce to a large extent the removal of the mercaptan-type odorant we were using. This removal is accelerated by the catalytic action of the iron oxide.

An investigation of the literature and a study of our previous experience indicated clearly that the hot oil fogger, which utilizes the principle of obtaining oil fog by suddenly cooling a hot gas stream carrying oil vapor, produces a fog of maximum stability and carrying power.

Seven fogging considerations

Our experience with oil fogging, covering a number of years, had brought to light many features which it appeared should be incorporated in the design of a hot oil fogger to obtain continuous trouble-free operation, adequate control of fogging rates and maximum fog stability. These factors are briefly as follows:

1. No heat should be applied directly to the oil. The necessary heat should be supplied to the "sweep" gas before contracting the oil to be vaporized. In this way the possibility of the carbonization of the oil on heat transfer surfaces with consequent adverse effect on fogging rates is avoided.
2. The heated gas should preferably be made to flow counter-current to the oil in order to obtain maximum vaporization of the oil for a given sweep gas flow and temperature.
3. In order to adequately control the fogging rate, the fresh oil should be added to the heated gas stream in a positively controlled manner which eliminates any possibility of flooding and over-fogging.
4. In order to maintain constant fogging rates, the spent oil residue should be removed continuously from the vaporization tower of the fogging equipment and not permitted to return to or mix with the fresh fogging oil.
5. The hot gas carrying the oil vapor should be introduced directly into the main gas stream. In this way the gas is cooled rapidly and a high concentration of fog particles is avoided and coalescence thereby reduced.
6. Open flames should be eliminated to reduce fire and explosion hazards. This permits the installation of these foggers at the most advantageous locations.
7. As a further safety measure, the heating of large volumes of oil in the fogger should be avoided. The design should also permit the storage of fogging oil at any convenient, safe location.

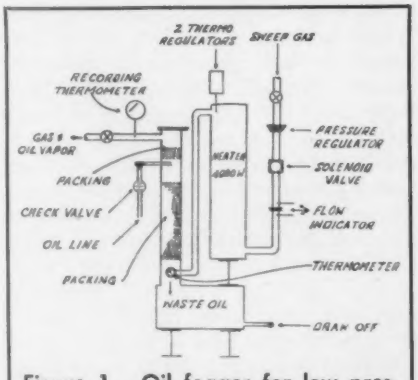

Figure 1. Oil fogger for low pressure stations, designed to fog 7.5 gals. of oil per day. Sweep gas 800-1,000 cu. ft. per hr.

We were unable to find on the market a hot oil fogger meeting these requirements. Foggers were therefore developed, incorporating the indicated features. Extensive experience has been secured by our operating department with all three types with entirely satisfactory results.

The first drawing shows a small fogger designed for an outlying station where oil requirements are limited to a few gallons per day.

This fogger was designed to operate at a station where the gas pressure is reduced. The sweep gas is passed through the fogger from the high to the low pressure main and the gas flow is controlled by adjusting the pressure regulator shown on the right of the drawing.

A solenoid valve follows the pressure regulator. With this arrangement the operation of the fogger can be made entirely automatic by connecting a timing device.

Following the solenoid is an orifice which may be used with either an indicating or recording flowmeter to measure the flow of sweep gas.

The cold sweep gas enters the bottom of the electric heater which has a capacity of four to five thousand watts. This type of fogger may be operated with a gas-fired or steam heater if it is desirable.

It is important that the gas pass up through the heater and that the thermoregulator controlling the gas temperatures be located at the top of the heater. With this arrangement, if the gas flow should be interrupted, heat from the heating elements will rise and the thermoregulator will cut off the current. As a further safety measure, we have employed two thermoregulators connected in series and arranged so that if the controlling regulator should fail, the second will operate at a temperature 50°F higher.

The temperature of the gas at this point is usually maintained at 350° to 400°F. However, it has been determined that temperatures as high as 500°F may be employed without decomposition of gas or oil. Use of higher temperatures permits increasing fogging rates substantially.

In passing up through the tower packing, counter-current to the oil flow, the hot gas heats and vaporizes the oil. The gas should leave the top of the tower at temperatures of 300 to 400°F, depending upon the boiling range of the fogging oil.

From this point the hot gas with oil vapor passes through an insulated line to the main gas stream where it is rapidly cooled by

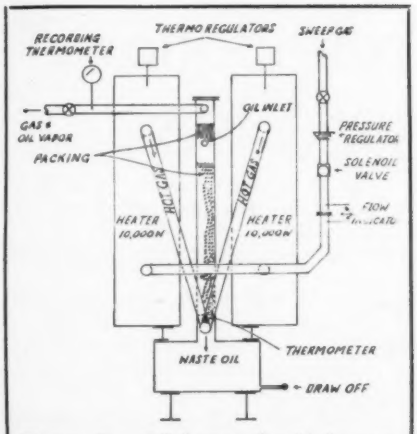

Figure 2. Oil fogger for high pressure stations designed to fog 10 gals. of oil per day. Sweep gas 5,000-6,000 cu. ft. per hr. Designed to operate at 150 psig and 400°F.

mixing with the cold gas, thus producing a stable fog. It is important that this line should be as short as possible. If a long line is required, heat should be added in order to prevent cooling of sweep gas and the condensation of oil vapor.

Approximately three inches of packing are placed in the tower above the point of introduction of the oil to reduce to the minimum the quantity of unvaporized oil carried in the gas stream.

The fogging rate is controlled by the rate at which oil is delivered to the tower.

We have followed the practice of supplying the oil by means of a small controlled volume pump equipped for adjustable feed rates.

Fresh oil is added continuously to the vaporizing tower and the unvaporized residue is collected in a reservoir at the bottom, out of contact with the gas stream. Not more than 80 to 90 per cent of the oil added should be vaporized in order that the residue may remain fluid and drain readily from the tower packing. The percentage of the oil vaporized may be controlled by either changing the sweep gas rate or the operating temperature.

The second drawing shows a fogger of the same type which was, however, designed for a distribution system operating at 100 to 120 psig.

The seven-fold increase in gas pressure requires the use of approximately seven times the quantity of sweep gas to secure the same oil vaporization rate as that obtained in a low pressure fogger.

The third drawing shows a large oil fogger designed for use at our principal distribution center where steam is readily available.

In this installation the sweep gas is heated by steam in a heat exchanger. In this design the oil is atomized into free space between layers of Raschig rings. This arrangement was used because we thought that the residue from the larger volume of oil for which this fogger was designed might clog a thick bed of tower packing. Experience has shown this precaution was not necessary.

The sweep gas rate has been about 20,000 cubic feet per hour and the oil fogged has averaged 50 to 60 gallons per day. During the past winter this fogger operated continuously without a single interruption. The oil residue drained from the bottom has been held at 20 to 25 per cent of that added. No solid residues have accumulated in the Raschig rings.

When foggers of this type were first placed in operation, the distance of travel and distribution of the fog were carefully studied.

Distance tests

The last fogger discussed, when placed in operation, was fogging oil at a rate of 50 gallons per day, which was equivalent to ¾ of a gallon of oil per million cubic feet of gas. When oil had appeared at four test points in the distribution system and could be definitely identified as fogging oil, these distances from the fogger were noted:

Northeast test	2.4 miles
North test	8.8 miles
East test	3.9 miles
South test	6.1 miles

Two additional test locations were installed and fogging oil was found:

Northeast test	7.5 miles
West test	5.25 miles

The excellent stability and transit of the fog produced by this equipment are also demonstrated by the fact that only negligible amounts of oil have been found in the mains close to the fogging locations. The excellent control is further demonstrated by the fact that no excessive oil has been found in customer service lines located close to the fogging points.

The fogging oil we use is a paraffin base oil which has been acid washed and distilled. It is made from selected stock to assure stability. Its distillation range is:

1 per cent over	587°F
5	596
20	601
50	610
70	623
90	646
99.3	668

The viscosity of the oil is approximately 50 seconds at 100°F, Saybolt Universal.

It has been our practice to condition new or dry systems with oil fog at a rate of 1½ to 2 gallons of oil per million cubic feet of gas. We believe about one gallon per million is sufficient once the system becomes oil wet.

Because of the high stability and carry of the fog made with this equipment these quantities are usually adequate. Higher fog concentration should be employed with caution because of possible trouble due to oil at customers' appliances.

Summary of results

It has now been more than two years since straight natural gas was first introduced into our system. We have had no evidence of dust movement or trouble in any part of the system and have had no indication of more than the usual negligible leakage from our mains. A further benefit has resulted in that we have experienced only minor difficulty in obtaining sufficient concentration of the mercaptan-type odorant in all parts of our distribution system.

Our experience on several occasions has definitely established the fact that an oil wet system is a "must" for maintaining desired odorant concentration.

Based on these considerations, we believe that our extensive gas conditioning program, which includes humidification as well as oil fogging, has paid dividends in good service and freedom from trouble.

NOTE: Application has been made for letters patent covering the novel features of the apparatus and method described herein. —EDITOR.

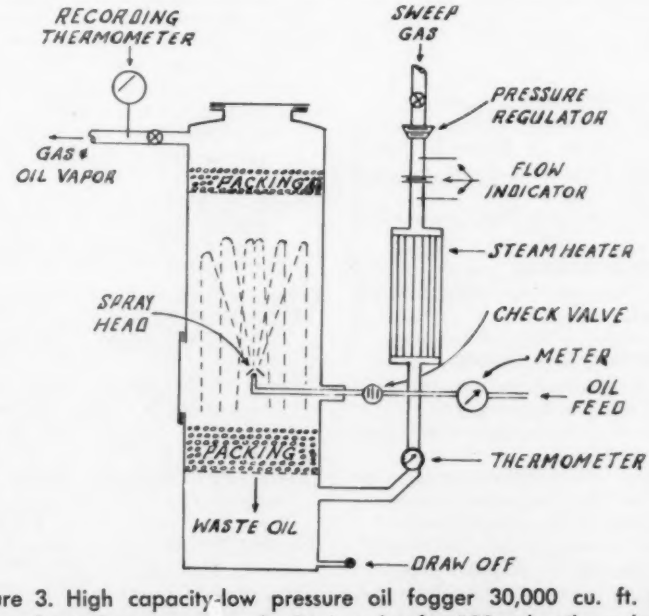

Figure 3. High capacity-low pressure oil fogger 30,000 cu. ft. steam heated sweep gas per hr. Designed to fog 100 gals. oil per day.

Bibliography of Technical Presentations Before Gas Associations, 1953-1954

THESE presentations were made before gas association groups since October 1, 1953. They are arranged by subject and, where it seemed appropriate, are included under more than one subject heading.

Copies of these presentations are *not*, in all cases, available for general distribution. The extent and manner of their availability must be determined individually through the associations.

The associations before which these presentations were made are indicated, in all entries, by abbreviations for the names of the associations:

AGA . . . American Gas Association
420 Lexington Avenue
New York 17, N. Y.

NEGA . . New England Gas Association
10 Newbury Street
Boston 16, Mass.

PCGA . . Pacific Coast Gas Association
2 Pine Street
San Francisco 11, Cal.

SGA . . . Southern Gas Association
1932 Life of America Bldg.
Dallas 2, Tex.

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GAS TURBINE DRIVEN CENTRIFUGAL COMPRESSORS FOR GAS TRANSMISSION—E. A. Walsh—AGA.

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APPLICATION OF FIRE CONTROL AND SLUG PURGE FOR PIPELINE MAINTENANCE—W. H. Krammes—AGA.

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(See also PLASTIC PIPE, FITTINGS)

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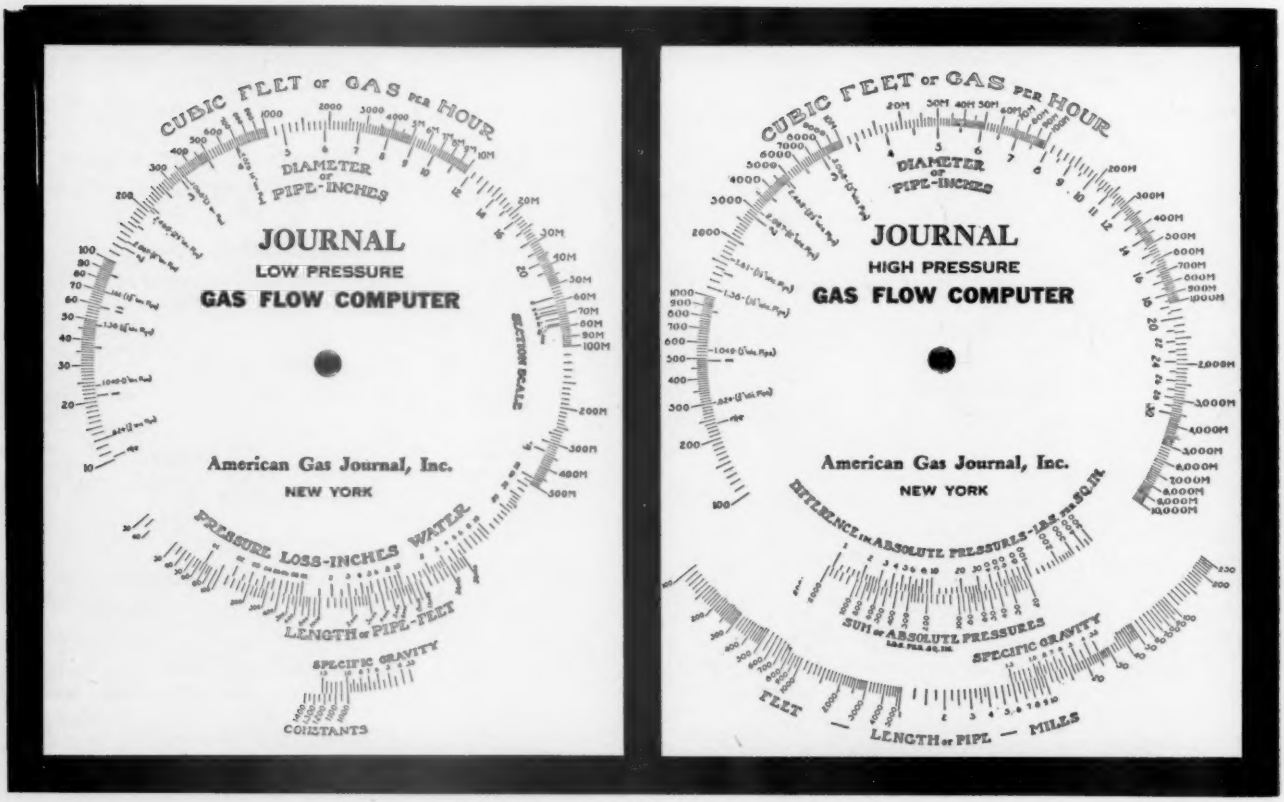
AMERICAN

Gas Journal

GAS FLOW COMPUTERS



FOR LOW PRESSURES

Cubic feet of gas per hour.....10 to 500M

Pipe diameters.....¾" to 48"

Pressure loss (inches)..... .01 to 10

Specific gravities.....1.5 to .35

Constants.....1400 to 1000

Pipe length (feet).....30 to 30,000

FOR HIGH PRESSURES

Cubic feet of gas per hour.....100 to 10MM

Pipe diameters.....¾" to 30"

Difference in absolute pressure to.....500 psi.

Sum of absolute pressures.....20 to 2,000 psi.

Specific gravities.....1.5 to .35

Pipe length (feet).....100 to 5,000

Pipe length (miles).....1 to 250

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AMERICAN Gas Journal

205 EAST 42 STREET—NEW YORK 17, NEW YORK

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best quality cyclic sulfide for every type of system

Gas engineers throughout the country wrote the specifications for Calodorant "C". It is the only natural gas odorant that is completely stable in high pressure lines—1000 psi or more—and at low temperatures—0° F or lower. Works equally well at medium and low pressures.

ALERT "80"

best economy-priced top quality mercaptan for utilities

Alert "80" has proved successful in all types of distribution systems under today's more demanding operating conditions. It has met every system test by large and small utilities over the past two years.

Contact the Oronite office nearest you for complete, detailed product information.

Oronite Gas Odorants are warehoused at plants convenient to any gas utility.

2091

The Best Gas Odorant Service

Q. Have you discovered the easiest way to "room test" your system?

The Oronite *ODOROMETER* is your answer. Hundreds are in use by utilities all over the country. Why not have an Oronite Gas Odorant specialist show you what can be done with the Odorometer.

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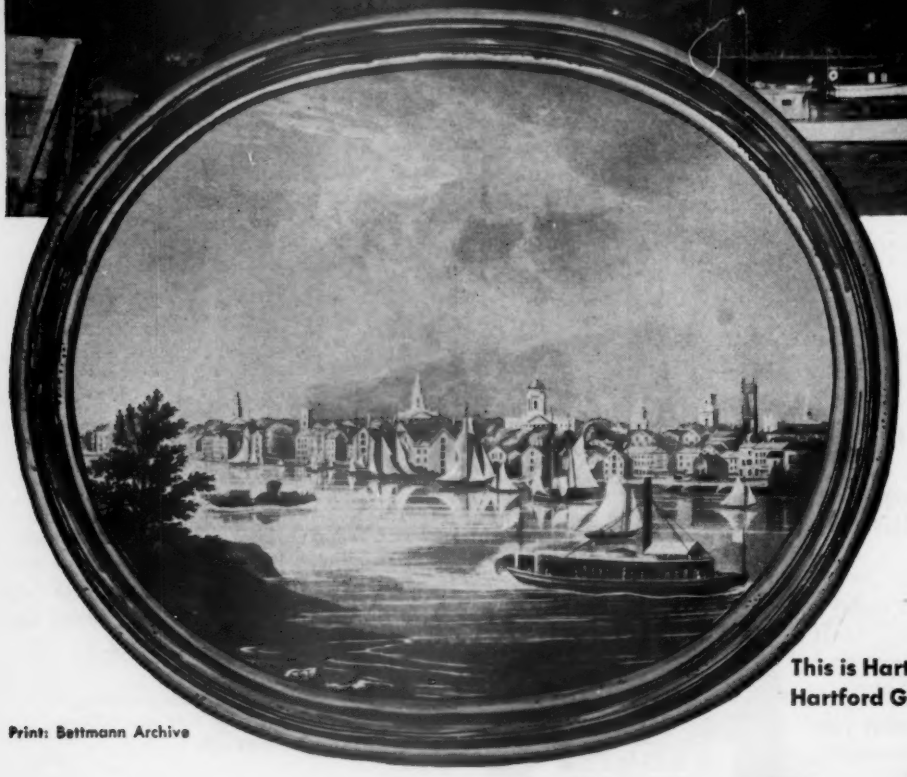
ORONITE CHEMICAL COMPANY

Once a customer

Photo: Black Star

This is Hartford, Conn., the "Insurance Center of the Western Hemisphere".



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This is Hartford as it looked in 1848 when Hartford Gas Company was founded.

MODERNIZED cast iron

ALWAYS a customer—generation after generation!

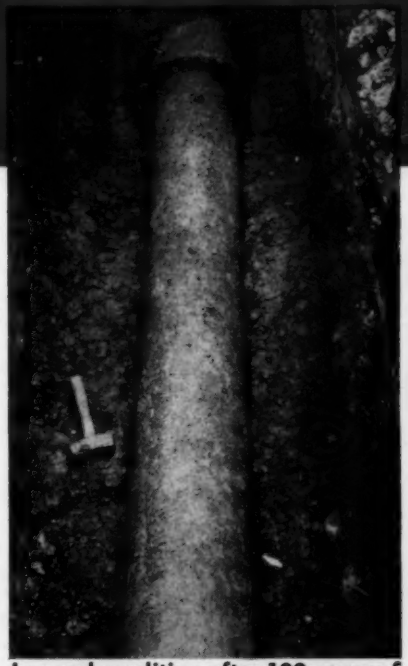
HARTFORD GAS COMPANY bought cast iron pipe 100 years ago—and buys it today

Hartford Gas Company (formerly Hartford City Gas Light Company) was granted its original charter in 1848. Population of Hartford was then 18,000. In 1849 cast iron distribution mains were laid. One of these mains recently was uncovered and found in good condition after 100 years' service (see cut). Today, this progressive Company is serving 67,000 customers with 535 miles of mains. It has recently completed conversion to a new 800 B.T.U. mixed gas to meet the needs of Greater Hartford's more than 300,000 population.

A famous jurist defined *good will* as "the probability of the customers' returning to the old stand." Hartford Gas Company has been buying cast iron pipe for more than a century. And, even though the pipe they laid in 1849 was made without benefit of engineering specifications, metallurgy and modern quality controls, some is still in service.

Today's *modernized* cast iron pipe—centrifugally cast and with standardized mechanical joints, is even more economical and efficient. The pipe is stronger, tougher, more uniform in quality. The mechanical joints are bottle-tight for usual gas pressures and for all types of gas.

Cast Iron Pipe Research Association, Thos. F. Wolfe, Managing Director, 122 So. Michigan Avenue, Chicago 3, Ill.



In good condition after 100 years of service, this cast iron gas main is still functioning as part of Hartford Gas Company's modern distribution system.

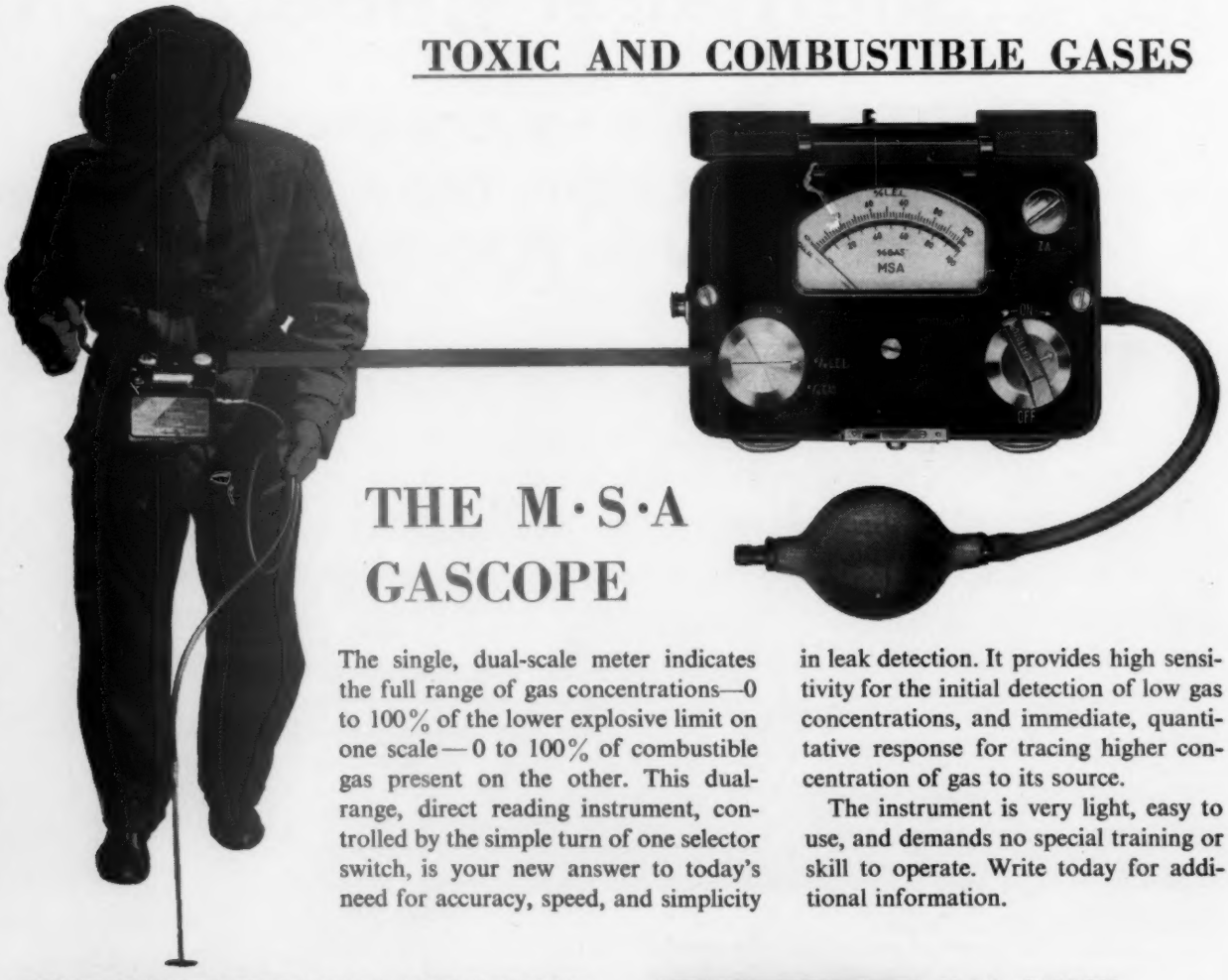
CAST IRON

The Q-Check stencilled on pipe is the Registered Service Mark of the Cast Iron Pipe Research Association.

pipe FOR MODERN GAS DISTRIBUTION

M·S·A INSTRUMENTS *for accurate detection, measurement and control of*

TOXIC AND COMBUSTIBLE GASES



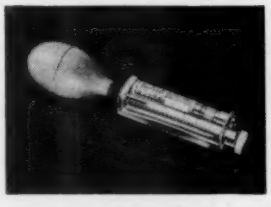
THE M·S·A GASCOPE

The single, dual-scale meter indicates the full range of gas concentrations—0 to 100% of the lower explosive limit on one scale—0 to 100% of combustible gas present on the other. This dual-range, direct reading instrument, controlled by the simple turn of one selector switch, is your new answer to today's need for accuracy, speed, and simplicity in leak detection. It provides high sensitivity for the initial detection of low gas concentrations, and immediate, quantitative response for tracing higher concentration of gas to its source.

The instrument is very light, easy to use, and demands no special training or skill to operate. Write today for additional information.

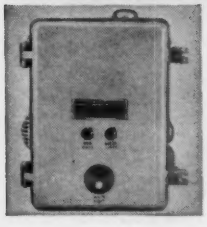
M.S.A. EXPLOSIMETER

Ideal for the detection of combustibles in manholes, detecting and locating leaks in distribution systems, and for use in general service inspection. Convenient one-hand operation; designed for day-in-day-out use. Write for details.



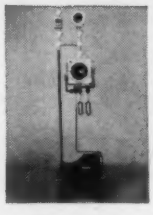
M.S.A. CARBON MONOXIDE TESTER

The CO Tester indicates CO in air from 0.001 to 0.10 percent by volume and is accurate in the presence of water and gasoline vapors. With a scrubber, it can be used for measuring CO in flue gases. Write for details.



M.S.A. CARBON MONOXIDE ALARM

Whenever CO reaches a predetermined concentration, this instrument sets off a loud, audible warning and visible indication. Ideal protection in gas manufacturing plants, pumping or compressor stations and around gas holders. Write for details.



M.S.A. COMBUSTIBLE GAS ALARM

Safe, continuous sampling of atmospheres for combustible gas and vapors in gas plants, compressor stations, and in gas holder areas. Listed by Underwriters' Laboratories for use in Class I, Group D locations. Visual and audible warning. Write for details.

ALSO—Lira Infra-red Gas Analyzers, Oxygen Indicators, Hydrogen Sulphide Detectors. Write for bulletins.

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SAFETY EQUIPMENT HEADQUARTERS

Call the M.S.A. man on your every safety problem . . . his job is to help you

MINE SAFETY APPLIANCES COMPANY

201 North Braddock Avenue, Pittsburgh 8, Pennsylvania

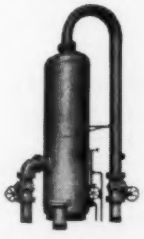
At Your Service:
82 Branch Offices in the United States and Canada

no screens to clog

no cyclones to fail

BLAW-KNOX gas cleaners

immediately wash dust with oil



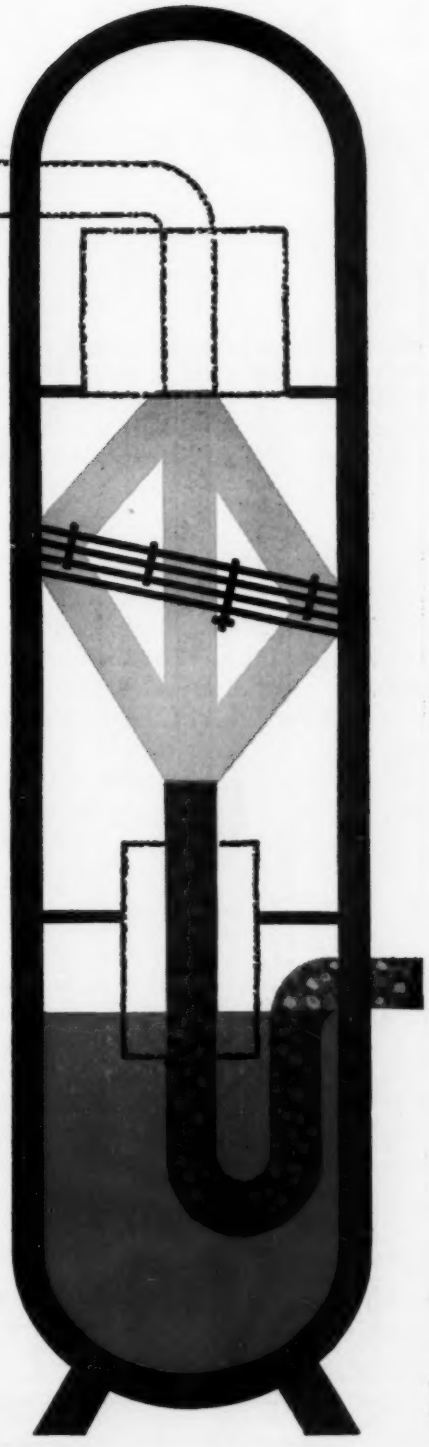
Blaw-Knox Gas Cleaners are engineered and built to remove dusts of all sizes under the most severe operating conditions with an absolute minimum of attention. There are no screens to clog or cyclones to errode and fail, reducing operating efficiency.

Immediately upon entering a Blaw-Knox Gas Cleaner, dust is violently, intimately washed with oil. The major portion of the heavier dust particles are actually scrubbed from the gas during this initial stage.

Remaining tiny wet dust particles are caught and agglomerated by a multiple baffle, primary separator. This separator is kept clean and operating at peak efficiency by continual recirculation of oil which washes particles down into a dust reservoir.

Finally, the gas flows through another expansion separation stage and into a multiple vane extractor which scrubs it clean of oil mist.

Traveling at high velocities, microscopic particles of pipeline dust sandblast regulators, compressor parts and metering devices, resulting in replacement costs, loss of revenue and customer ill will. Clean gas costs you less. So, when you buy, specify a Blaw-Knox Gas Cleaner and be sure that you're removing dusts of all sizes.

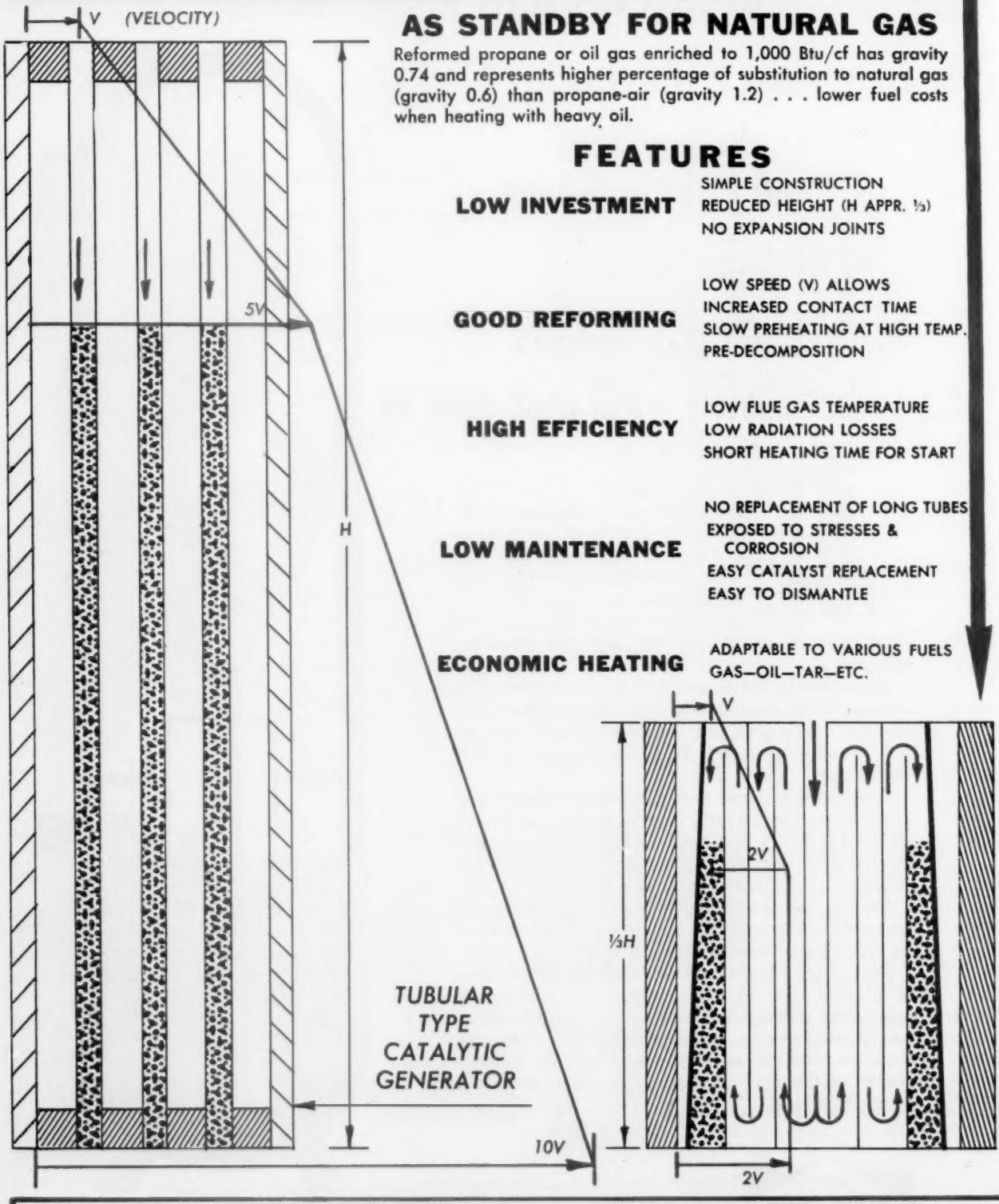


BLAW-KNOX

BLAW-KNOX COMPANY *Blaw-Knox Equipment Division*

Gas Equipment Department • Pittsburgh 38, Pennsylvania

CONCENTRIC CATALYTIC GENERATOR



AS STANDBY FOR NATURAL GAS

Reformed propane or oil gas enriched to 1,000 Btu/cf has gravity 0.74 and represents higher percentage of substitution to natural gas (gravity 0.6) than propane-air (gravity 1.2) . . . lower fuel costs when heating with heavy oil.

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- NO EXPANSION JOINTS

GOOD REFORMING
- LOW SPEED (V) ALLOWS INCREASED CONTACT TIME
- SLOW PREHEATING AT HIGH TEMP.
- PRE-DECOMPOSITION

HIGH EFFICIENCY
- LOW FLUE GAS TEMPERATURE
- LOW RADIATION LOSSES
- SHORT HEATING TIME FOR START

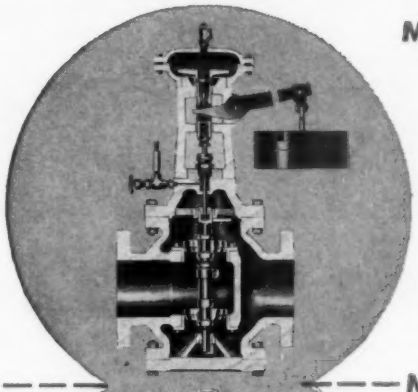
LOW MAINTENANCE
- NO REPLACEMENT OF LONG TUBES EXPOSED TO STRESSES & CORROSION
- EASY CATALYST REPLACEMENT
- EASY TO DISMANTLE

ECONOMIC HEATING
- ADAPTABLE TO VARIOUS FUELS GAS—OIL—TAR—ETC.

NORTH AMERICAN UTILITY & CONSTRUCTION CORP.

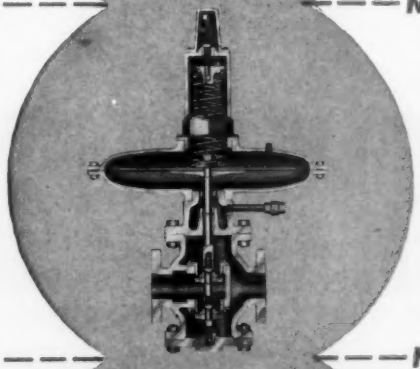
CHRYSLER BUILDING NEW YORK 17, N. Y.

Chaplin-Fulton
PRESSURE REGULATORS
a complete line for every requirement



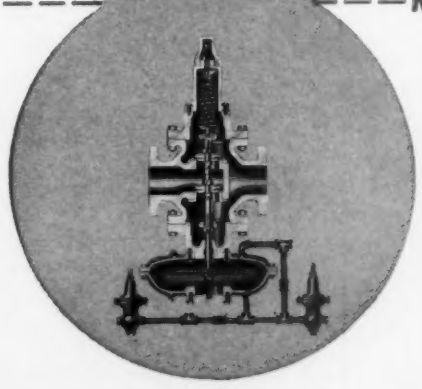
MODEL 44
Weight and Lever Loaded

For general pressure reduction service. Sizes 2″-12″ standard, 16″-24″ special. Flanged body assemblies in cast iron for 100 lb. or 600 lb. W.P.—cast steel for 1200 lb. W. P. Controlled Pressure Range—ounces to 200 lbs. All flanged construction—lubricated stuffing boxes—removable orifices—balanced valve assemblies interchangeable—hard seat, soft seat or reduced size—all center guided.



MODEL 44 S
Spring Loaded

A dependable, accurate regulator for distribution service, large industrial or commercial applications, boilers, industrial furnaces, dehydrators, etc. Sizes 2″-6″, flanged F&D 125 lb. body assembly for 100 lb. W. P. Controlled Pressure Range—ounces to 50 lbs. Can be furnished as zero governor. Removable orifices, soft seat balanced valve construction, easily adjustable and removable. Springs colored for identification.



MODEL 44 PC
Pilot Loaded

An accurate efficient pressure loaded regulator for high or low pressure service. Town border settings, compressor fuel lines, transmission measuring stations, large industrial installations. Sizes 2″-12″, flanged for 100 lb., 600 lb., or 1200 lb. W. P. Controlled Pressure Range—ounces to 400 lbs. All flanged construction. MODEL 44 PC—closes on pilot pressure failure. MODEL 44 PO—opens on pilot failure.

OTHER BALANCED VALVE TYPES

Model 44D Duplex Gas Regulators
Model 44B Back Pressure Regulators
Model 44 Diaphragm Motor Valves
Model 46 Industrial Furnace Regulators
SENSITROL Pilot Loading Systems

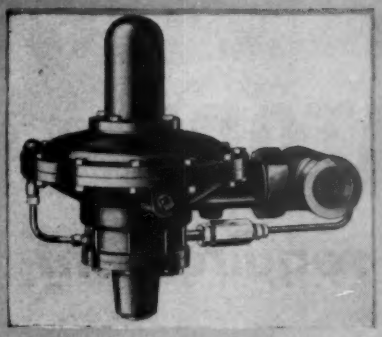
SINGLE SEAT REGULATORS

Little Hercules High Pressure
H. P. Field Regulator Type 101
House Regulators with Cut-off
H. P. Spring Field Type 149
Dead Weight Pressure Regulators
C-F Type 250 Safety Valves

LONG IN OPERATION • LOW IN MAINTENANCE

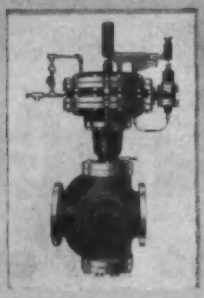
ACCURATE CF MFG CO *DEPENDABLE*

Chaplin-Fulton
MANUFACTURING COMPANY
Pittsburgh 25, Pennsylvania



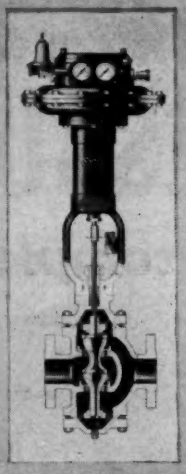
TYPE 99

Self-contained pilot-operated gas regulator for small border stations and industrial applications. 2" size only. Reduced pressure range 4 ozs. to 65 lbs.



TYPE 840

The Fisher King Booster is an entirely self-contained pressure controller. It will maintain a constant pressure at the low pressure point in the distribution system regardless of demand load.

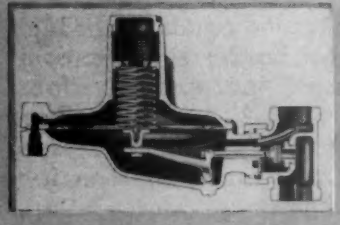


TYPE 4100D-57T

High-pressure reducing valve for border stations—high-pressure regulation and industrial applications.

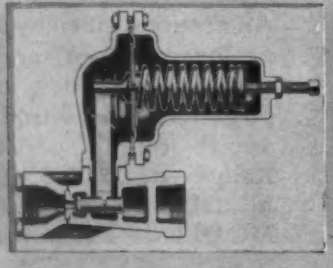
AMERICA'S BEST

FISHER® America's



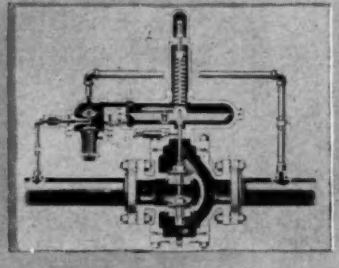
TYPE 730C

Standard gas service regulator with or without integral relief valve, bug-proof vent. Sizes ¾" to 2".



TYPE 630

"Big Joe" pressure regulator for high-pressure field and pipe line installations. Sizes 1" and 2". Reduced pressure range 5 to 200 pounds. Inlet pressure up to 1000 lbs.

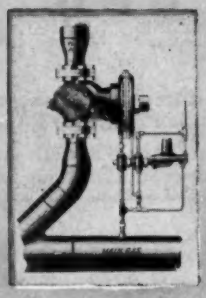


TYPE 298

Pilot-operated gas pressure regulator—non-bleed construction—for border station and district regulator applications, for low and intermediate pressures. Sizes 2" and up.

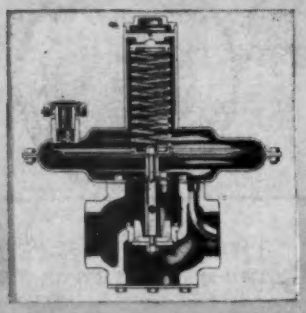
FISHER GOVERNOR

LEADS THE INDUSTRY IN RESEARCH FOR



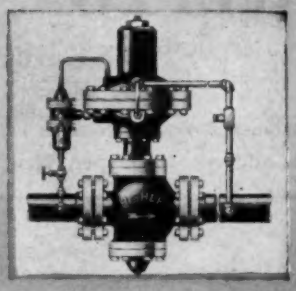
TYPE 29

Full capacity relief valve for distribution systems where large volumes may be discharged without a substantial increase in system pressures. For complete protection against excessive pressures.



TYPE 66

Low-pressure sensitive industrial regulator for inlet pressure up to 5 lbs. Reduced pressure "WC to 1 lb. Sizes 2", 3", and 4".



TYPE 880

High-pressure gas regulator with no bleed to atmosphere, for border stations, loop lines, and big industrials. Extreme stability combined with excellent performance.

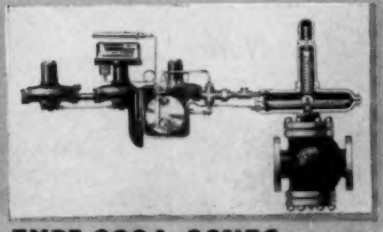
GAS MEN PREFER

Best Gas Regulators

The Industry's Most Complete Line

Fisher Governor Company's wide variety of regulators handle control applications ranging from the natural gas well head to burner utilization. Illustrated are just a few of the varieties of construction.

This complete Fisher line of regulators for the gas industry includes District Regulators, high, low and intermediate pressure — Distribution Regulators — House Service Regulators—High Pressure Field Regulators—Boiler Gas Fuel Governors — Booster Regulators — Safety Shut-Off Regulators—Town Border Station Regulators—Industrial Gas Regulators—Meter Run Regulators.



TYPE 298A-831LTC

As a district regulator the Fisher Time Temperature Booster will automatically increase the low pressure when the temperature drops to compensate for the increased load of residential heating. It automatically lowers the pressure during high-temperature periods.

COMPANY • Marshalltown, Iowa

FISHER

Since 1880

BETTER GAS PRESSURE CONTROL

SAFETY GAS MAIN STOPPER CO.

STREET DEPARTMENT SUPPLIES

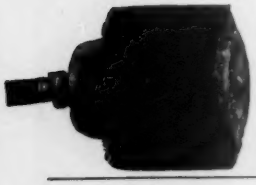
523 Atlantic Avenue, Brooklyn 17, N. Y.
Cable Address: Gastopper, New York

Pac. Coast Rep.: C. B. Babcock Co., 384-7th St., San Francisco 3, California
New England Rep.: Eastern Appliance Co., 281 Vassar St., Cambridge 39, Mass.

Standard Sizes in Stock

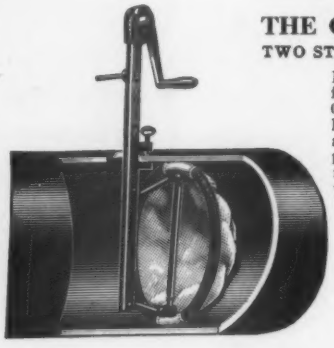
Special Sizes on Short Notice

PIPE CLEANING BRUSHES



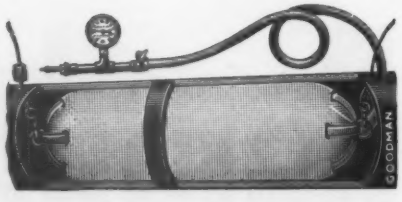
THE GOODMAN-PEDEN STOPPER

TWO STYLES—WITH OR WITHOUT PLUG



In the Goodman-Peden Stopper the flexible frame, padding, covering and diaphragm of Goodman Stopper remain in principle, but the handles have been discarded and in their stead a new arrangement in construction makes it possible to operate the stopper mechanically rather than by the experience and skill of the workman. Made in standard sizes.

GOODMAN CYLINDRICAL STOPPERS



This is an inflatable bag with a fine, strong waterproof casing for use in gas and oil pipes. The broad central zone making contact with the wall of the pipe keeps the bag from creeping or slipping.

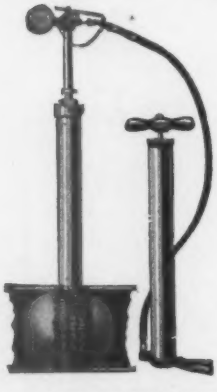
It may be inflated to a high internal pressure and will hold against 60% as much pressure in the main.

This stopper is pulled into place by cables. It will hold back more pressure than any other bag.

Sizes, 2 inch to 48 inch in stock.

Special sizes to order.

GARDNER-GOODMAN STOPPERS



A stopper for low and intermediate pressures.

For use on cast iron or steel, oversize or undersize mains.

Easily inserted in top, bottom or side of main, in open excavation or under pavements.

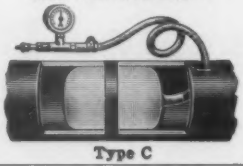
For pressure work, use two or more stoppers in parallel.

Sizes, 2 inch to 20 inch.

DEPENDABLE GAS MAIN BAGS

PLAIN RUBBER

CANVAS COVERED



Type C

For the present, we have discontinued the manufacture of all types of bags except Type "B" Plain Rubber (medium weight) and Type "C" Canvas Covered Bags.

Type "C" for use in mains coated with tar or oil and wherever a plain rubber bag would not hold. This canvas-covered bag consists of an inner bag of fine quality rubber, strong and expansible, encased in a cover made of best quality U. S. Army duck. **Gauge of Rubber and strength of duck suited to each size.** Bags correctly fashioned and covers finely tailored insure a snug fit and a good shut-off when the bag is inflated in the pipe. Fitted with tire valve, nipple, hose clamp and thumb screw. **Inflate** as you would a tire. **To deflate** pull out the **valve.**

Pipe Plugs Many Types

Spring Heel Plugs

Tape for Emergency Repairs

A valuable aid to have on hand to bandage up breaks in mains and services. Repairs made this way will hold for long periods if necessary. Bandage with Soap Tape and cover with Binding Tape Strips 2", 4", 6", 8".

U.G.I. Cyclic Catalytic Reforming Process*

Carburetted and Blue Water Gas Plants

Mechanical Generators and Chargers

Automatic Control Machines

U.G.I. Heavy Oil Process

Waste Heat Boilers

High Duty Condensers

U.G.I. Equipment

UNITED SERVICES PROVIDE

EXPERIENCE IN DESIGN

United has over 70 years' experience in gas industry construction.

EFFICIENT APPARATUS

United has pioneered major developments in city gas and synthesis gas production, catalytically and thermally.

ECONOMICAL CONSTRUCTION

United has large, well-organized forces for natural and manufactured gas construction work.

EXPERIENCE IN OPERATION

United has experienced plant operators for securing most efficient results from apparatus.

Gas Main and Pipeline Construction

High Btu Oil Gas Apparatus

General Gas Plant Extensions

L.P. Gas Plant Equipment

Natural Gas Handling Equipment

Producer Gas Plants

U.G.I. CYCLIC CATALYTIC REFORMING PROCESS* APPARATUS

The U.G.I. C.C.R. Process is a flexible, high capacity, economical process for reforming natural gas, L.P. gases, naphtha, kerosene, gas oil, and heavy oil. It has the flexibility to produce utility gases ranging from 380 to 1,000 Btu, ammonia synthesis gas and other reformed gases to meet many of the requirements of the gas and chemical industries.

The Process has been in commercial operation for five years and is now in operation in eight plants on 16 installations. The process is an adaption of the efficient cyclic principle used for years in the production of blue and carburetted water gas. The operating requirements are simple.

The investment cost is low. Installations can be made on a new site or in utility plants where further economies are secured through an installation adjacent to existing water gas equipment and through conversions of water gas sets where existing services are utilized to the fullest extent.

U.G.I. MECHANICAL GENERATOR CARBURETTED AND BLUE WATER GAS SETS

The U.G.I. Mechanical Generator is established as a rugged, reliable, and efficient self-clinkering generator, that makes an important contribution to betterment of gas plant labor conditions. Over 140 installations have been made.

U.G.I. Water Gas Apparatus is the result of over seventy years' experience in design and operation of gas plants. It offers maximum efficiency with minimum cost of labor and maintenance. Automatic control, self-clinkering generator and fuel charger provide complete automatic operation. Lowest cost raw materials available to plant can be used.

CONSTRUCTION-INSPECTION SERVICES FOR GAS MAIN AND PIPELINE CONSTRUCTION

United's construction-inspection services for pipelines and distribution mains can supplement your distribution department's forces during the most active part of your construction program. It can operate as an adjunct to your inspection and supervision or to handle definite portions of the construction.

Well qualified men of long experience are provided, who, in addition to being qualified technically for their work, are experienced in handling and taking part in large construction operations. They are backed by a responsible organization with a wide construction background.

The services assist in bringing to your organization the latest techniques and methods of construction and gives you assurance, at reasonable cost, that the work will be carried out in accordance with your specifications and your high standards of security and safety.

GENERAL GAS PLANT EXTENSIONS

Through the years United has built up large well organized and experienced forces for handling extensions to general gas plant facilities, including gas handling and treating equipment, compressors, boilers, buildings and foundations, and additions and reinforcements to plant electric and mechanical services.

No matter what your project, we invite you to share our experience and facilities as designers, contractors, and consulting engineers.

* Patents Pending

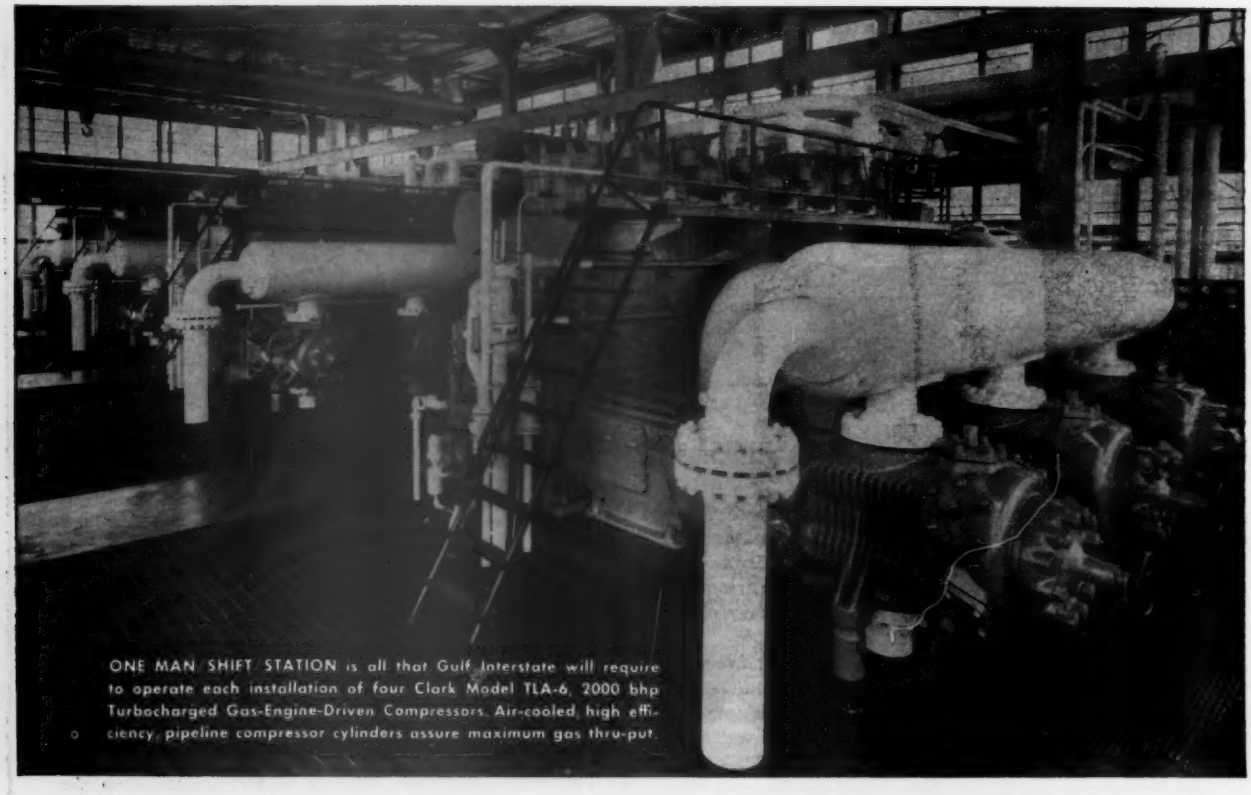
UNITED ENGINEERS & CONSTRUCTORS INC

NEW YORK 17 PHILADELPHIA 5 CHICAGO 2

WITH A BACKGROUND OF OVER SEVENTY YEARS' EXPERIENCE

NEW GULF INTERSTATE SYSTEM

Selects the Clark Turbocharged Model TLA-6 for its Automatic, Push-Button Operated Stations



ONE MAN SHIFT STATION is all that Gulf Interstate will require to operate each installation of four Clark Model TLA-6, 2000 bhp Turbocharged Gas-Engine-Driven Compressors. Air-cooled, high efficiency, pipeline compressor cylinders assure maximum gas thru-put.

It's already an accepted fact that the Gulf Interstate Gas Company has changed the pattern for natural gas transmission with its one man, push-button controlled, automatic compressor stations.

With such advanced thinking, it's only natural that Gulf Interstate will be the first to use the NEW Clark Model TLA, 2000 bhp, Turbocharged Compressors in conjunction with their newly developed system of controls.

Gulf Interstate's control devices for automatic operation of these Clark Compressors did not appreciably increase the installed cost.

If you're interested in a compressor station that can be operated with the highest possible efficiency — *automatically* — while still maintaining station-loading flexibility, be sure you investigate Clark Models TRA and TLA Compressors. There are 8 sizes in a range of 825-3300 bhp. Ask your nearest Clark representative for Bulletins 130 and 134.

CLARK BROS. CO. • OLEAN, N. Y.
ONE OF THE DRESSER INDUSTRIES
Sales Offices in Principal Cities Throughout the World

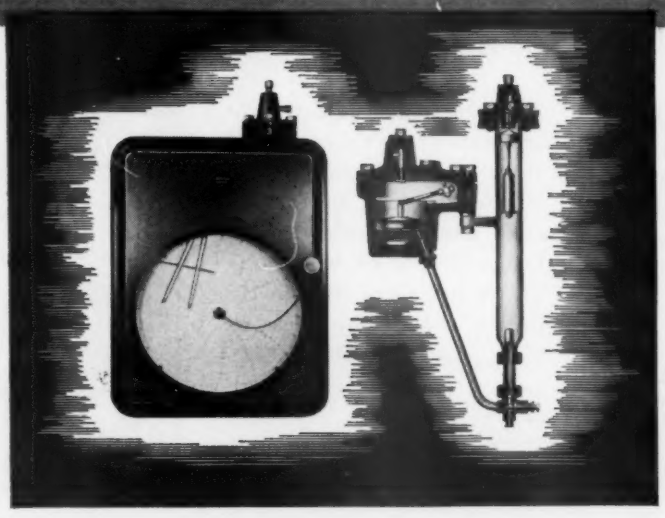
A dozen ways you'll be ahead with Clark TLA's

- **7000 btu/bhp/h fuel consumption.**
- **40% less cooling required.**
- **25-30% lower installation cost.**
- **Drastic reduction in number of moving parts.**
- **90% engine mechanical efficiency.**
- **Detonation-free operation under all climatic conditions.**
- **Generous temporary overload capacity.**
- **Specifically designed for turbocharging.**
- **Low cycle temperatures for maximum cylinder and ring life.**
- **Only one turbocharger per unit.**
- **Unapproached for accessibility.**
- **2-cycle simplicity, dependability.**

CLARK compressors

Clark sets the pace in compressor progress

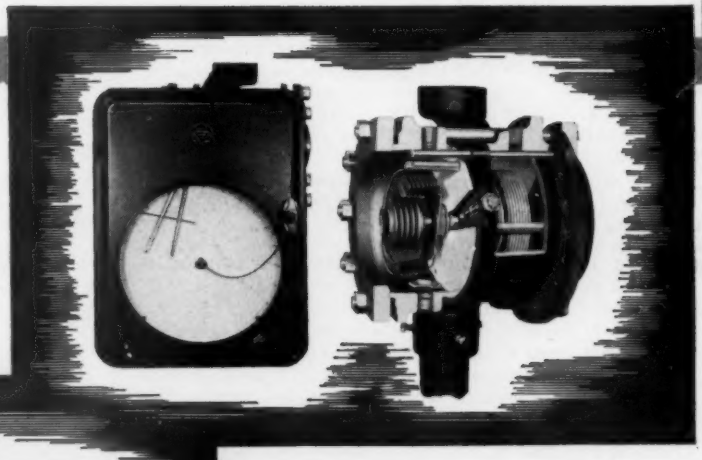
IF YOUR PROBLEM IS
precision gas measurement...



AMERICAN-WESTCOTT SERIES A-88 MERCURY ORIFICE METERS are synonymous with accurate and dependable measurement with operating pressures to 5000 P.S.I. Available in 10", 20", 50", 100" and 200" differential range manometers, with recorders having square root or direct reading charts. Integrating instruments totalize fluid quantities, integrating both static and differential pressures. Indicating instruments show rate of flow where records are not required.

Mercury manometers feature interchangeable differential range tubes and American Teflon Seal Stuffing Boxes that never require lubrication.

AMERICAN DRI-FLO MERCURYLESS ORIFICE METERS for applications where mercury manometers are not desired. Available in 20", 50", 100", and 200" ranges, with working pressures to 1000 P.S.I., ambient temperatures of —25° to 175° F.



AMERICAN DISPLACEMENT GAS METERS are the "cash registers" of the gas industry. In millions of home, community and industrial installations these units are giving accurate, dependable and economical measurement. Produced in Ironcase, Tinned Steelcase and Aluminumcase models to meet various pressure and installation conditions, and for measurement of different types of gases in high or low flow rates.

AMERICAN METER COMPANY

INCORPORATED ESTABLISHED 1836

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RESEARCH CORPORATION

Plant: Bound Brook, New Jersey

BRANCH OFFICES: *405 Lexington Ave., N. Y. 17, N. Y.* • *Grant Building, Pittsburgh 19, Pa.*
122 So. Michigan Ave., Chicago, Ill. • *111 Sutter St., San Francisco, Cal.*

The COTTRELL PROCESS of Electrical Precipitation for Detarring Manufactured Gas

Cottrell Electrical Precipitation Equipment has established itself by its successful performance record in the Gas Industry as a standard means of detarring gas which claims the confidence of engineers and executives seeking maximum results at minimum costs. Over 300 installations of this equipment are in use in carburetted water gas plants and by-product coke oven gas plants handling a total of over 3½ billion cubic feet of gas per day.

Equipment Used for Detarring

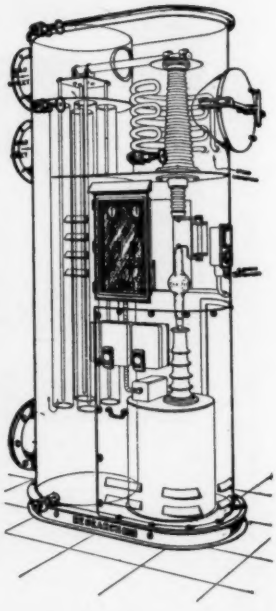
The precipitator for this service is usually constructed with a cylindrical shell in which are grouped collecting electrode pipes either 6" or 8" in diameter, depending upon the size of the unit, through which the gas passes. These precipitators are constructed in a number of different sizes so that any gas cleaning capacity may be obtained by utilizing one or more of these standard size units.

In the operation of the precipitator, the tar and oil, which is suspended in the gas as a fog or mist, is driven out of the gas by the electrostatic action and collects on the inside surfaces of the pipes. The collected tar and oil being free flowing, flows readily from the pipes so that the precipitator is self cleaning. The electrical power consumed in the operation of the precipitator is small, averaging 5 to 8 Kw hours per million cubic feet of gas cleaned, and the pressure drop across the precipitator is only ¼" to ½" H_2O.

Carburetted Water Gas

In carburetted water gas plants the precipitator is usually located after the exhausters so that the gas is handled at a pressure range from 1" to 3" Hg and at a temperature range from 70°F. to 125°F. at the inlet to the precipitator. Actual tests show removals ranging from 95 to 99% of the tar, oil and entrained water with a pressure drop of less than a quarter of an inch of water across the precipitator. This effective tar removal has greatly improved and reduced the cost of subsequent gas purification. Where dry purification is used the elimination of the tar ahead of the purifier has increased the sulphur conversion, reduced the fouling of the oxide and eliminated caking of the beds.

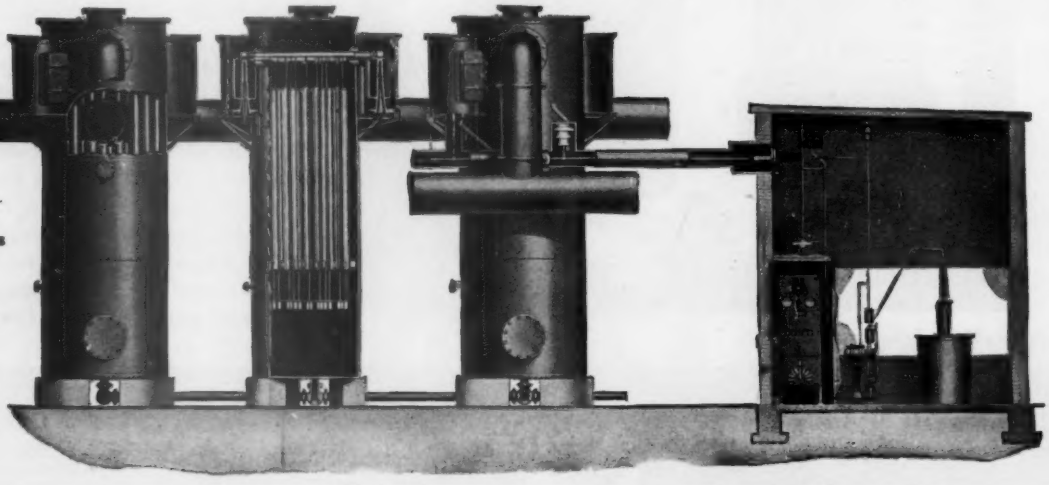
By-Product Coke Oven Gas



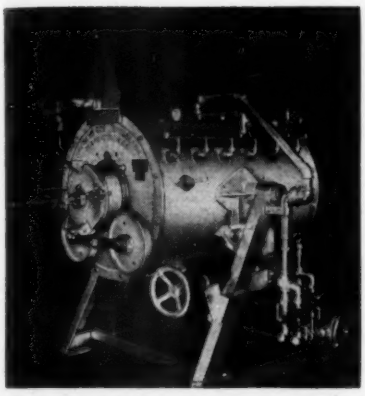
The precipitators for coke oven gas in some instances are located ahead of the exhausters while in other instances they are located after the exhausters so that pressure at which the gas is treated will range from 1" Hg suction to 3" Hg pressure. In all cases the precipitator follows coolers so that temperature ranges from 70°F. to 125°F. These units show tar removals ranging from 95 to 99%. As a result there is less contamination of the sulphate, less fouling of the circulating liquor in the light oil recovery towers, and less difficulty in the distribution and utilization of the gas.

Small Gas Plants

A Cottrell Precipitator Unit (shown above) is particularly suited for the small gas plants with capacities ranging from 500,000 to 2,500,000 cubic feet of gas per day. The electrical equipment for this unit is placed in a steel shell which is fabricated integrally with the precipitator shell. The entire unit is shipped completely assembled ready to be placed upon the foundations. As a result Cottrell Equipment can now be offered that will satisfy the space limitations and economic requirements of the small gas plant.



Exterior and Interior Details of Typical 3 Unit Detarring Precipitator



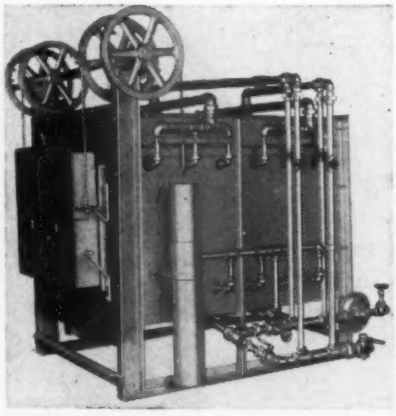
FURNACES by AGF

Automatic Heat Treating Equipment and Accessories

ROTARY BATCH CARBURIZERS

The Batch Type furnace (shown above) is highly flexible in that it can handle atmosphere or general work in independent charges for hardening, annealing, and normalizing of metal products, also calcining and roasting of paint pigments, drying or burning abrasives and oxide reduction. Extremely economical, the various sizes of this rotary furnace are adaptable to almost any work where absolute uniformity is essential.

The originators of much of the industrial gas controlled atmosphere equipment in use today, AGF engineers and metallurgists are well qualified to recommend the proper equipment for your purpose. A few of the more popular types of furnaces are illustrated and described.



OVEN TYPE FURNACES

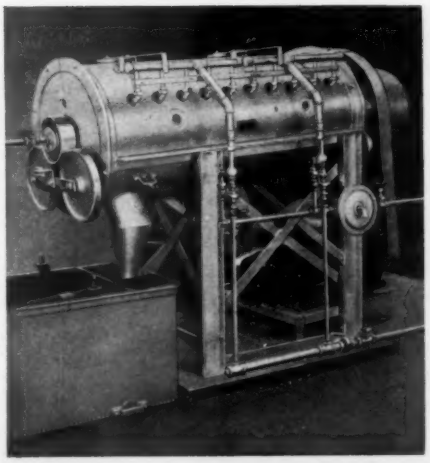
The large oven type furnace (shown at the left) is used for annealing, hardening, carburizing and a wide range of controlled temperature work from 1300 to 1800° F. Special Oven Type furnaces can be had for temperatures up to 2500°. The liberal placing of independently operated burners in AGF Oven Type Furnaces makes them models of low gas consumption and efficiency.

PRODUCTS

ANNEALING EQUIPMENT
BLOWPIPES
BURNERS
BURNER TIPS
CARBURIZERS
DISSOCIATORS
FIRES: CROSS, GLASS, HAND
FLOW METERS
FORGES
FURNACES: ANNEALING
ATMOSPHERE
AUTOMATIC
BRAZING
CYLINDRICAL
MUFFLE
OVEN, POT
RECIPROCATING
ROTARY, SALT-BATH, TUBE
VERTICAL
HEATERS: SOLDERING IRON, RIVET
MACHINES: HEATING, AUTOMATIC HEAT TREATING, QUENCHING
ROLLER HEARTH
MELTERS
MIXERS
PRESSURE GAUGES
RATIO SETS
TORCHES
ZERO GOVERNORS
AND MANY OTHER PARTS AND ACCESSORIES

CONTINUOUS ROTARY HEATING MACHINES and CARBURIZERS

The rotary type of Continuous Clean Hardening Furnaces have the special feature of mixing the work as they automatically advance it through the retort thus assuring uniform heating of all the work. Used for uniform carburizing, clean hardening, annealing and other heat treating, these Rotary Retort Furnaces are equipped with automatic controls for variable temperatures and heating time cycles.

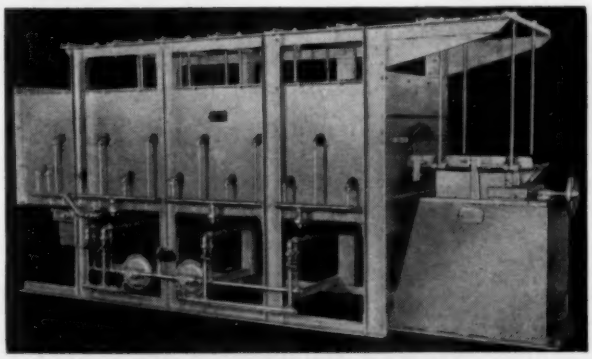


RECIPROCATING HEARTH HEATING MACHINES (AUTOMATIC)

A popular controlled Atmosphere Furnace that clean hardens from 10 to 1200 pounds per hour of such products as tools, springs, pins, stampings, etc. In operation the full muffle swings from the superstructure and an automatic mechanical movement at the end of each stroke advances the work. Any desired heating time can be obtained by simple adjustment.

SPECIAL MACHINES and EQUIPMENT

AGF engineers are able to combine standard and special equipment, even with that of other manufacturers where practical to obtain a desired result in production or perfection of work. Ask about many examples of special installations.



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Write for your nearest point of service. Direct factory service where not represented.

WRITE FOR latest Bulletins upon AGF Furnaces, Equipment and Accessories. For general information ask for Catalog No. 606

AMERICAN GAS FURNACE CO.
132 SPRING STREET — ELIZABETH 4, N. J.

"PIONEERS SINCE 1878"

POSEY IRON WORKS, INC.

STEEL PLATE DIVISION

LANCASTER — PENNA.

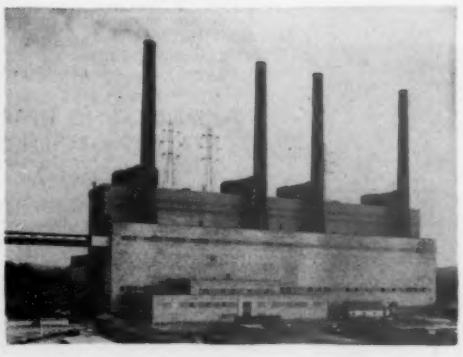
NEW YORK OFFICE • GRAYBAR BLDG.

A Partial List of Posey Iron Products

Autoclaves · Barges · Bins · Butane-Propane Tanks · Condensers · Digesters · Dredge Hulls and Pipe · Dryer Shells · Elevated Tanks (Steel and Alloy Steel) · Fabricated Steel Plate · Gas Holders · Kilns · Pressure Vessels · Retorts · Stacks · Stand Pipes · Stills · Storage Tanks (Steel and Alloy Steel) · Welded and Riveted Pipe · Wrought Iron, Steel and Alloy Steel Pipe.

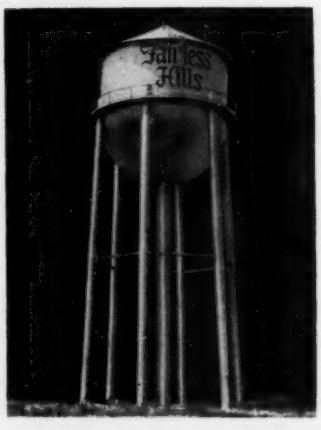
Posey Iron builds high and low pressure vessels for both liquids and gas.

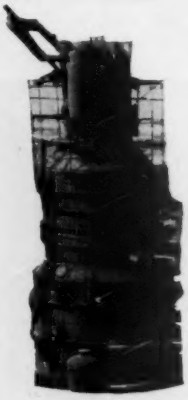
Posey Iron stainless clad digester is shown mounted on truck enroute to user. 13' O. D. x 40' long.



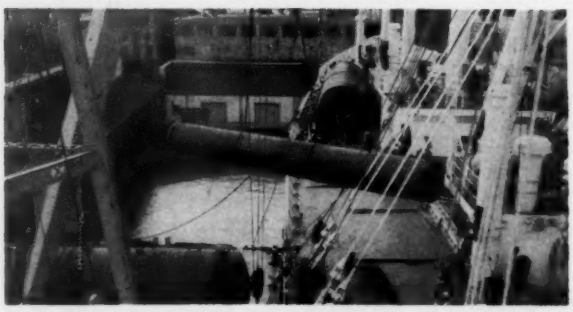
These four stacks by Posey Iron measure 23' diameter by 192'-6" high.

250,000 gallon water tank stands 105 feet above ground. Supplied with water from wells 65 to 75 feet underground.





Vacuum tower for crude distilling fabricated throughout by Posey Iron Works.

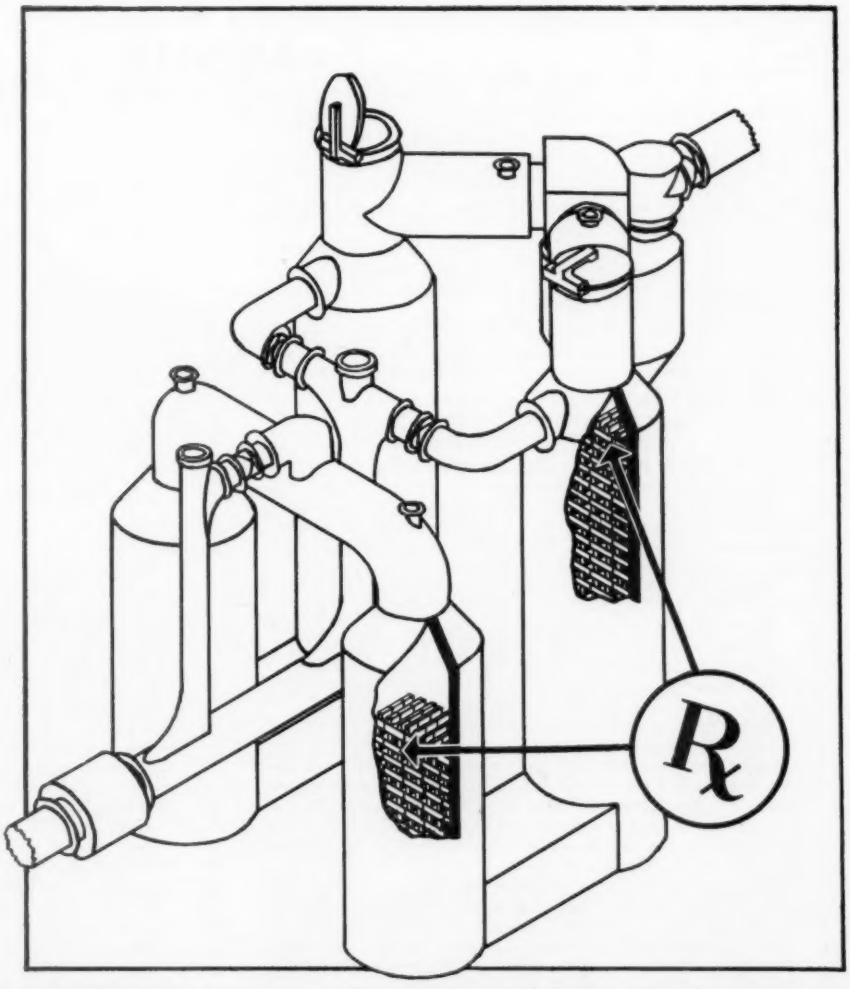


Horizontal storage tanks being loaded aboard freighter for export. Many Posey Iron installations are overseas.

DIVISIONS: BRICK MACHINERY · FOUNDRY · HEATING · IROQUOIS · SHIPBUILDING · STEEL PLATE

Rx

for maximum oil-gas make under toughest service conditions . . .



High BTU oil-gas equipment offers a serious challenge to any refractory brick. Norton CRYSTOLON checker brick is *engineered* to meet this challenge with efficiency-boosting service — and is *prescribed* for the top 5 or 6 courses, as shown in the diagram.

Here's a Norton Rx — a time-tested "Refractory Prescription" — that will do a lot towards increasing both the daily gas make and the service life of your oil-gas generators: *Use* CRYSTOLON* *checker brick.*

Like all Norton Rx Refractories, CRYSTOLON checker brick is carefully engineered for its particular jobs. That's why its high refractoriness and abrasion resistance, plus quick storage and release of heat, offer such big advantages in your gas making equipment. For example: longest service with least possible spalling and breaking up — and fewest shutdowns for inspection, repairs or replacements.

Put These Advantages To Work For You! For top gas make at lowest cost, get complete details on CRYSTOLON checker brick from your Norton Representative. Or write direct to NORTON COMPANY, 905 New Bond St., Worcester 6, Mass. *Canadian Representative:* A. P. Green Fire Brick Co., Ltd., Toronto. Ontario.

And These NORTON Rx Refractories Cut Costs Too...

CRYSTOLON Brick for Cross Overs and Carburetors

For these applications CRYSTOLON brick — in circle brick, special circles and straights — have proven highly successful. Also where heat or abrasion resistance is important — as in some spots in carburetors and checkers in water gas operations — CRYSTOLON brick insures low cost operation.

ALUNDUM Plates for Hasche Generators*

High purity ALUNDUM Plates (99% Al_2O_3) are the best obtainable for use in the Hasche process for gas reforming or hydrocarbon cracking.

ALUNDUM Catalyst Carriers for Gas Reforming

ALUNDUM (alpha alumina) Catalyst Carriers are being used extensively for nickel impregnation in gas reforming. Their strength, uniformity (of structure and size) and inertness make them outstanding for applications of this type.

CRYSTOLON Cements for Insulation and Patching

For patching or for new installation in places where it is difficult to install brick, CRYSTOLON cements, including a new air setting cement, are highly recommended.

NORTON
REFRACTORIES
Engineered...Rx...Prescribed
Making better products... to make other products better

*Trade-Marks Reg. U. S. Pat. Off. and Foreign Countries

ANDALE

Heat Exchangers . . . Strainers . . . Valves

HEAT EXCHANGERS

Gas Coolers, Aftercoolers,
Air Coolers, Aftercoolers,
Oil Coolers, Lubricant circuit,
Oil Coolers, Quenching oil,
Jacket Water Coolers,
Condensers, Ammonia,
Condensers, Process Vapor,
Condensers, Carbon Dioxide,
(Heaters, Unfired).
Fuel Oil Heaters,
Feed Water Preheaters,
Tar Heaters,
Waste Heat Recovery,
Stills,
Reboilers

Tube Bundle type only. Standard Designs. Special Designs. Standard and Special Materials.

Tubes seamless, cold drawn. Tube ends expanded metal-to-metal in both tube sheets.

Andale STANDARD Designs.

————With tube-bundles REMOVABLE:

One end or both ends floating.

With straight tubes. Tube bundles with same baffling, or with different baffling, are interchangeable in shells of the same design and size. Repairable. Both sides of bundle are cleanable, inspectable. Single pass and multi-pass.

Materials: Suited to the conditions in which the unit is to be used.

Tube lengths: 6¼″ to 192″.
Tubes: 1/4″ to 2½″ o.d.
Shells: 1″ to 72″ i.d.
For Pressures: Vaccuum to 900 lb. sq. in.
For Temperatures: 0°F. to 600° F.

This group of designs includes: Andale Type 202; with heads and tube bundle removable without need of disturbing the pipe connections for the tube stream; which connections are on the outer wall of the shell, and are permanent. Also Designs Type 202 Class IV; with the shell stream in a bored steel shell; with the tube stream touching only non-ferrous metal; with tube stream pipe connections permanent on ring at wall of shell (not on heads).

The various Series of Standard designs include units to serve in all usual (and many unusual) combinations of conditions and requirements. Designs to meet various problems of destructive conditions, water quality, corrosion, abrasion, etc.; and to meet limitations on water quantity, pressure loss, space, weight, etc.

————With tube-bundles NON-REMOVABLE:

With both tube sheets joined permanently to shell; no stuffing box at either tube sheet. Vapor tight or gas tight on shell stream, and tube stream. Steam or other vapor is at outer side of tubes. Some designs with bowed tubes; "Tar heater" types. Other designs with straight tubes. with expansion joint in shell wall.

Andale SPECIAL Designs.

For special results, gases, liquids, situations, operating conditions, controls, etc. Including units of larger size than in standard series. With all parts special, or incorporating some standard parts. With special designs of heads, shell, joint plan, connections, reflux, offtakes, separator, etc.

Special materials, as required.
Pressures: Vacuum to 5000 lb. sq. in.
Temperatures: Minus 100° F. to 1000° F.

We design and make tube bundle type exchangers to duty and material specifications of any department of Government; or to specifications of private industrial companies; to ASME boiler code or any State code; with manufacturer's data reports supplied; with inspection by authorized inspectors of the department or company concerned, by National Board boiler inspectors, or by insurance inspectors. We do not make exchangers to designs not made by us.

We do not issue a catalog of exchangers. Each offer is a design selected by us to meet best the user's requirements and conditions.

STRAINERS. For:

——Oil:
Lubricant Circuit
Fuel; before burner
Cargo
Pipe Line
Storage
Refinery
Aviation Gasoline
—Suction
—Steam
—Process Liquids
—Product Liquids, Paints, etc.
—Recovery of Wanted Solids

——Water:
Sea
Tidal
Harbor
Freshet
Trashy
Well
Corrosive
Contaminated, (Sewage etc.)
Plant Intake
Plant Service lines
Ship Service lines
Municipal Services

——Protection of:
Close Bearings: in Machines, Engines, Generators, etc.
Sensitive Instruments
Pumps
Heat Exchangers
Filter beds
Tanks
Reservoirs
Sprinkler Systems
—Grease Extracting*
—Feed Water Filter*
*(With wrapped Baskets).

With straining openings from 0.0055″ (0.0029″ in some cases); to 3/8″ or larger. Pressures: from suction to 900 psi. Temperatures to 1200 deg. F. Materials suited to the conditions.

BASKET Type Strainers

Baskets removable. Interchangeable. Bodies: cast iron, bronze, cast steel. Tested to 50% over stated rating.

————Single compartment. Simplex. Macomb bodies and other designs. No valve.

————Two-compartment. Duplex. Switchable; with valve integral. Valves disc type or plug type.

——With DISC Type switching valves (two), with globe seats. Rising spindles, outside screw and yoke. One valve controls outlets of the two compartments; other valve controls their inlets. With or without Chain Interlock on the two valves.

——With PLUG Type switching valve (single plug). With Jack in yoke to lift and seat plug. Any turning movement of plug controls simultaneously the inlets and outlets of both compartments. Also made for remote control.

————BASKETS. Styles supplied in strainer bodies: Bucket type. Side-inlet type. Perforated. Mesh. Single wall. Double-wall separable. Designs to be wrapped.

WHEEL Type Strainers

For Water. (Fresh or Salt. With or without Sewage Contamination). Rotary. Continuous flow. Backwash pressure and volume are independent of main stream. Wash boxes are at *both* sides of grid wheel. Backwash flow can be adjusted to quantity of dirt to be washed from grid. Rotating element is completely of stainless steel. Strains through triangular openings in revolving grid. Openings have inscribed-circle-diameters 0.031″ to 0.125″. Strainer sizes for 600 to 25,000 gpm net strained stream.

VALVES

————Duplex Threeway (6 connections); for pressure line. Single plug. Jack in yoke lifts and seats plug. Connections are: main inlet; main outlet; outlet to circuit A, inlet from circuit A; outlet to circuit B, inlet from circuit B. Also made for remote control.

————Threeway (3 connections). Disc type; globe seats. Outside screw and yoke. Angle stem. Position of stem end indicates flow direction.

————For Constant Pressure on Varying Flow. To keep pressure constant* in pipes from which the flows at points of use may vary sharply or be closed completely; (*constant within limit set by the input). Automatic. By sensitive continuous release of surplus.

For promptness, thoroughness, accuracy of service; we request:—In first communication, order or inquiry, relating to any item of equipment, please describe, as completely as possible, the situation in which it is to be used.

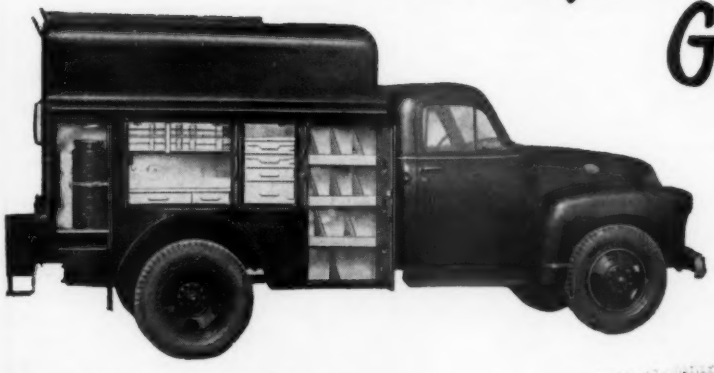
ANDALE Company

1768 Cherry Street, Philadelphia-3, Pa. ————————Telephones: Philadelphia-LO-7-6830

The dependable name for Gas Utility Bodies

There are Holan body models for every type of gas construction, maintenance and service work. They have the latest engineering features that help your crews operate more efficiently.

The wide selection of Holan standard body models eliminates, in most cases, the necessity of ordering expensive special body models.



CL-112 Light Gas Construction and Maintenance Body

HOLAN

1051 Gas Construction Body

1090 Meter Service Body

1563 Compressor Body

FOR THE GAS INDUSTRY
HOLAN UTILITY EQUIPMENT

Gas Construction Bodies (with or without crew compartments)
Air Compressor Bodies
Crew Carrier Bodies
General Service Bodies
Gas Meter Installation Bodies
Appliance Installation Bodies
Winches and Power Take-offs

J. H. HOLAN CORPORATION

District Sales Representatives
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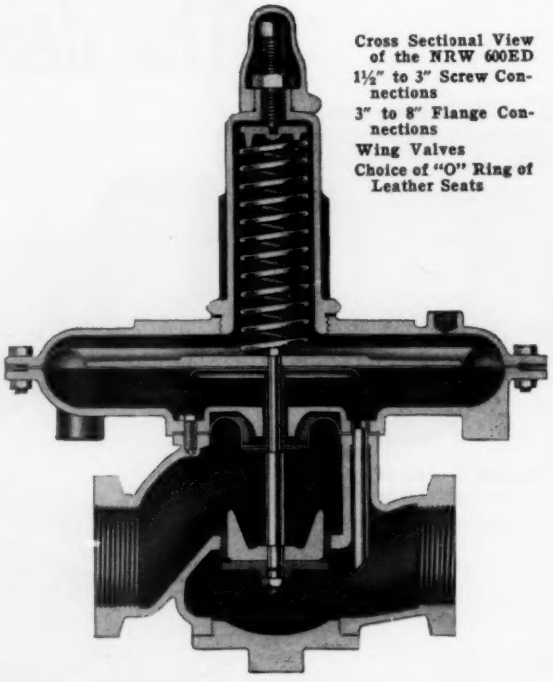
Hydraulic Derricks • Jacks
Ladders • Towers • Diggers
and Accessories for
Truck Bodies

REYNOLDS PRODUCTS

High Pressure Service House Regulators:
Straight Lever Type—Models 10-20 Series.
Toggle Lever Type—Model 30 Series
Low Pressure Service or Appliance Regulators
Intermediate Pressure Regulators
District Station Regulators, Double Valve
Auxiliary Bowl & Automatic Loading Device Optional
High Pressure Line Regulators
Toggle Type Regulators
Single Valve, Double Valve
Gas Engine Regulators
Seals: Dead Weight or Mercury
Relief Valves: High or Low Pressure.
Back Pressure Valves.
Automatic Quick-Closing Anti-Vacuum Valves.
Automatic Shut-Off Valves.
Lever Operated Valves.
Louver Operated Device
Atmospheric Regulators
Vacuum Regulators



Cross Sectional View of the NRW 600ED
1½" to 3" Screw Connections
3" to 8" Flange Connections
Wing Valves
Choice of "O" Ring of Leather Seats

REYNOLDS GAS REGULATOR CO., Anderson, Indiana, U. S. A.

Representatives:

H. D. "Mike" Meuffels
421 Dwight Building
Kansas City, Missouri

Seidenglanz & Co.
2nd Unit, Santa Fe Bldg.
Dallas, Texas

Eastern Appliance Co.
281 Vassar Street
Cambridge, Mass.

Waldo S. Hull
258 Lee Circle
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IRON SPONGE

for high efficiency gas purification at high pressures

Iron Sponge is your key to sulfur-free gas at minimum processing cost. Iron Sponge has high efficiency at low pressures or at today's high pressures and high temperatures. It absorbs *more* H_2S, gives long service between foulings, and is easily regenerated. Investigate it for your purification problem today!

CONNELLY, Inc.

3154 S. California Ave., Chicago 8, Illinois
Elizabeth, N. J. • Los Angeles, California

BTU CONTROL

provides two features —no time lag —low cost

the BTU CONTROL, is a recent addition to the caloroptic line! Designed to provide modulated control for your motorized valve by varying the BTU up and down . . . thus maintaining the proper standard.

CONNELLY, Inc.

Elizabeth, N. J. • Los Angeles, Calif.
3154 South California Ave., Chicago 8, Ill.

NEW EQUIPMENT

COMBUSTION EQUIPMENT

Gas burner nozzle

A new 8-inch size gas burner nozzle has been added to the manufacturer's line of nozzles for open port firing on industrial furnaces, kilns, driers, ovens, air heaters, boilers, immersion tubes and kettles. The nozzles are recommended by the company for blast firing of air-gas mixtures into open ports of furnaces, or for firing into the open without a combustion chamber, and where a small amount of excess air induced around the nozzle is allowable. The new 8-inch size offers a gas burning capacity up to 6,200,000 Btu/hr with 6" w.c. mixture pressure. The new nozzle supplements the previous line of 10 other sizes of nozzles from ½" through 6", inclusive.

Retain-A-Flame Gas Burner Nozzle. Hauck Mfg. Co., 124-136 Tenth St., Brooklyn 15, N. Y.

COMPRESSORS

Gas-engine-driven compressor

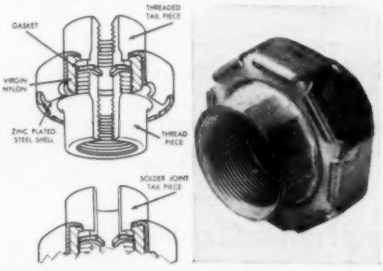
By applying turbocharging in the development of this new 2,000 hp gas engine driven compressor, the manufacturer reports that a 2,000 hp four-cycle unit has been made available which is compact in size and economical in performance. The crankshaft design, with compound crankpins, contributes to the weight and size reduction. Turbocharging, as applied to the new unit, is a combination of scavenging and supercharging by means of an exhaust-turbine-driven centrifugal blower. At the end of the exhaust stroke and beginning of the intake stroke, inlet and exhaust valves are open, permitting air from the blower to sweep through the top cylinder space, purging spent gases and cooling piston, valves and cylinder. When the exhaust closes for the remainder of the intake stroke, the cylinder is filled with compressed air at about 4 psi. The unit is provided with 2 Elliot turbochargers, each driven by the exhaust gases from the adjacent 6 power cylinders. Both blowers discharge into a common air intake manifold. The blower speed is proportional to the fuel consumed, making it self-regulating at all speeds and loads. The blower starts automatically when the engine begins to operate. Compression ratio of the engine is 6.1, resulting in a compression pressure of 225 psi and a firing pressure of 600 psi at 2,000 hp. The fuel rate is 7,600 Btu/bhphr at full load, according to the manufacturer.

Type 412 KVS, Turbocharged Gas Engine Driven Compressor. Ingersoll-Rand Co., 11 Broadway, New York 4.

FITTINGS

Pipe union

New sizes in insulating or dielectric pipe unions, which serve as unions and electric circuit breaks to stop the flow of stray electric current, have been introduced by the company and a range of sizes from ½" to 2" are now available. The units offer protection against galvanic corrosion and electrolysis in piping systems where any 2 dis-

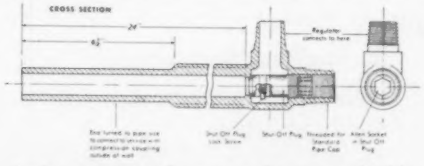


similar metal pipes are connected. Feature of the union is the insulating nut of zinc-plated steel shell containing nylon core. The insulating pipe unions are applicable in systems for gas, water, steam and all types of fluids.

Universal Controls Corp., 731 W. Davis St., Dallas 8.

Wall service fitting

A one piece wall service fitting reportedly designed to promote safety and economy in making services through walls, this

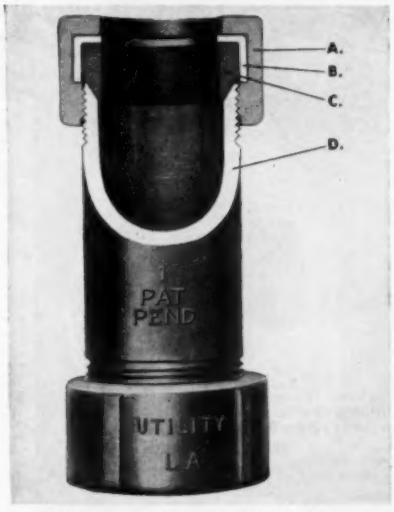


device consists of an extra heavy malleable iron tube with the end outside the wall turned to pipe size, to connect to the service pipe with a compression coupling. The part that passes through the wall is heavily ribbed, serving to anchor the fitting when grout is tamped around it and into the hole in the wall. Accidental extreme strain on the service line, the manufacturer reports, will thus cause it to pull off at the compression coupling rather than inside the building. The end inside the wall incorporates a branch tee and an angle valve of tamper-proof design, enabling the regulator or meter to be attached directly to the outlet of the fitting, saving a valve and thread joints. The fittings are available in ¾", 1" and 1¼" pipe sizes.

Wall Service Fitting. M. B. Skinner Co., South Bend 21, Ind.

Coupling

A compression pipe coupling for connecting small pipe, this coupling eliminates thread cutting since pipe ends are simply inserted into the factory assembled couplings and compression nuts tightened to complete the connection. Supplied in ½", ¾", 1", 1¼", 1½" and 2" sizes, the regular couplings have sleeve lengths from 2¾" to 4", increasing in size ¼" for each larger pipe diameter. Shorter or longer sleeve lengths are available. Sleeves (D), are supplied in black, galvanized or cadmium plated steel; stainless steel; Monel, Inconel; brass or bronze. Compression nuts (A), are made of ductile iron. Gaskets (C), either rubber or neoprene, are inserted



in steel retainers (B). Special gaskets available for any purpose.

Utility Clamp & Equipment Co., 108 W. 6th St., Los Angeles 14.

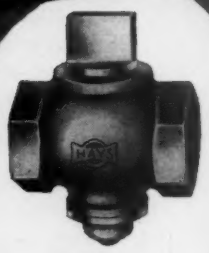
Connection sleeve—leak clamp

Described by the manufacturer as a new system for making pipe connections, the system involves sleeves for steel to steel

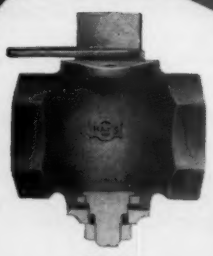
connections that become welded joints, sleeves designed for use with a new compound where welding is not practical, and a new leak clamp for bell joint repairs. The sleeves for steel to steel connections reportedly will withstand pressures up to 100 lbs. before welding, through the use of a seal ring. The pipe becomes a continuous welded construction or one end welded and the other an insulated joint. There are no flanges, bolts, collars, or rings to obstruct in final wrapping of sleeves. In low and intermediate pressure ranges the sleeves are said to eliminate interruption of service, loss of pressure and the use of plug-off equipment. The new compound for use on sleeves without welding, such as cast iron to cast iron, or steel to cast iron, is made of a heavy liquid synthetic. It chemically cures in 24 hours

for STOPS that are TOPS

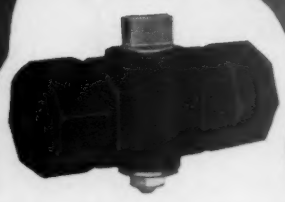
IT PAYS TO BUY HAYS



7405
Iron Body, Galvanized,
Bronze Plug Stop



7490
"Key-Lok" Tamper Proof Stop
Lockwing—Iron Body,
Bronze Plug



7500
Threadless Gas Stop
Iron Body, Brass Plug

Service Line Stops—Meter Stops
Appliance Stops

Tamper Proof and Standard Patterns

Iron Body with Brass Plug
Black or Galvanized
Also All Brass Stops

Flat Head—Flat Head with Lockwing

Full Range of Sizes

Quality Assured . . .
By Precision Machining—
Individual Testing—
Rigid Inspection

Quality Proven . . .
By Supplying the Gas Industry
for Over 80 Years

Standard Packaging for Easy Handling,
Space Saving Storage . . . Another HAYS First

Write for literature, or ask "The Man from Hays"

HAYS
GAS SERVICE PRODUCTS
HAYS MANUFACTURING CO.
ERIE, PA.

at 80° F, after an accelerator has been added. It forms a complete seal of adhesion to the pipe, and a 2½" adhesion joint is made when the compound has been pumped into the sleeve. The same compound is used on a new leak clamp for

bell-joint repair. This clamp, of two piece construction, acts as a mold and retainer for the compound and becomes a part of a molded joint.

United Pipe Utility Suppliers, Inc., Box 777, Beloit, Wis.

INSTRUMENTS, CONTROLS

Control drive

Gas and liquid flow regulation may be improved, the company reports, by use of its small, pneumatically-operated control drive. Butterfly valves, dampers and feeders may be operated on a straight-line flow characteristic. A pneumatic signal actuates a positioning relay which in turn accurately positions a piston-operated drive lever arm. The drive measures 10" by 11" by 19" and may be installed in any position on a column, pipe or flat surface. Time required for full travel, 75°, is adjustable. The drive has a 4" piston stroke at a torque of 75 ft-lb. It operates on standard SAMA signal ranges 3-15 and 3-27 psig. Standard connecting linkage is available.

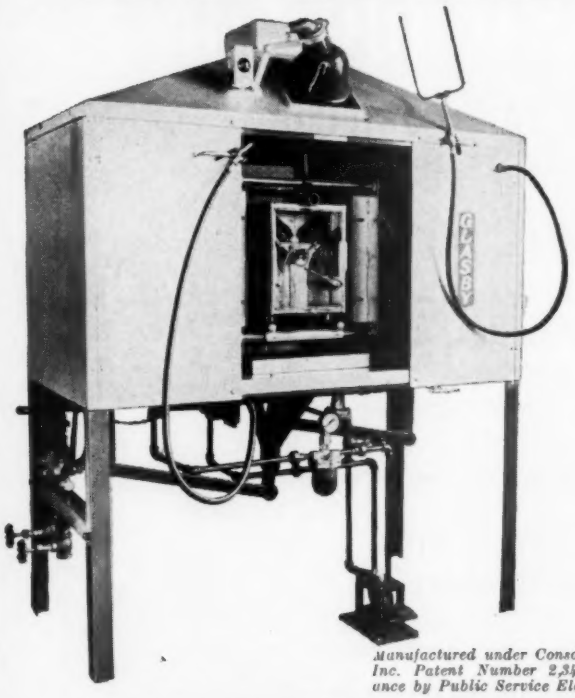
Bailey Control Drive. Bailey Meter Co., 1050 Ivanhoe Rd., Cleveland 10, O.

Recorder-controller

A new line of recorder-controller instruments with a wide range of industrial uses for applications which include recording

and control of temperature, conductivity, strain, force, position, pressure, and for telemetering, these instruments require no batteries or standardizing circuits and operate on the null-balance principle using AC

Precision Meter Repairs with Maximum Efficiency



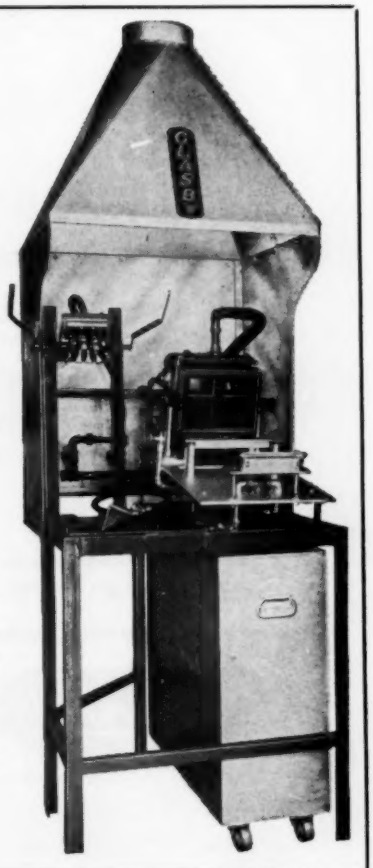
Minimum Repair Time
Means Maximum
Dollar Savings

← **Meter Front and Back Removing Machine**

This machine removes the front and back from gas meters in a fraction of the time previously required thus facilitating repair of diaphragms. Two models available—5 light meter and 10 light meter capacity. Both models are adjustable to most makes of meters and feature additional safety devices to protect the operator.

Meter Top and Valve Box Cover Removing Machine →

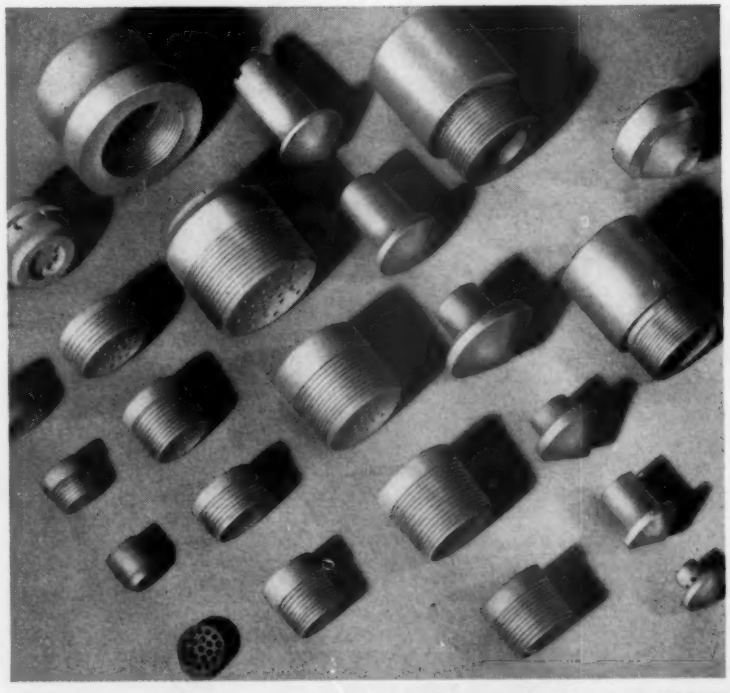
This machine facilitates the removal of meter tops and valve box covers to minimize the time-consuming problems of meter repair operation. Available in 5 light meter and 10 light meter sizes, both adjustable to most makes of meters. Both models feature devices for the safety of the operator.



Manufactured under Consolidated Edison Company of New York, Inc. Patent Number 2,342,045. Application development assistance by Public Service Electric and Gas Company of New Jersey.

THE J. P. GLASBY MFG. CO. INC.

BELLEVILLE 9, NEW JERSEY — *Manufacturers of Glasby Conversion Burners and Furnaces*



53RD YEAR OF CERAMIC LEADERSHIP

LAVA AND ALSIMAG GAS TIPS

TRADE MARK REGISTERED U.S. PATENT OFFICE

Industrial Gas Burners . . . Pilot Tips
Radiant Burner Heads . . . Carbon Black Tips
For All Combustible Gases

• ILLUSTRATED (at left) are only a few of the many hundreds of types of burners produced. Standard designs or custom made to your specifications. Hard, strong, non-carbonizing, non-corrodible, long lasting materials. Quality proved by more than 50 years of practical experience. Engineering collaboration gladly extended.

AMERICAN LAVA CORPORATION, CHATTANOOGA 5, TENNESSEE

it says **LOOK OUT**

MALLINCKRODT ETHYL MERCAPTAN PURIFIED

the powerful, skunk-scented gas odorant that gives you extra safety and savings

UNMISTAKABLE WARNING—the penetrating, skunk-like odor of Mallinckrodt Ethyl Mercaptan gives instant warning of the smallest gas leak

SAFE FOR YOUR EQUIPMENT—it's *purified* to make it safe for even the most delicate valves and gauges

NO HARMFUL PHYSIOLOGICAL EFFECTS—when breathed in normal concentrations, Mallinckrodt Ethyl Mercaptan causes no injury to eyes or mucous membranes

CONCENTRATED ECONOMY—just one pound will odorize a tankcar of LP or a million cubic feet of natural gas

EASY TO ADD—without expensive additional equipment, Mallinckrodt Ethyl Mercaptan can be easily added to your gas by either drip, absorption or by-pass

For more information, write to:

Mallinckrodt

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Mallinckrodt St., St. Louis 7, Mo. 72 Gold St., New York, 8, N. Y.

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Manufacturers of Medicinal, Photographic, Analytical and Industrial Fine Chemicals

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THE FIRST REALLY *New* PIPE FINDER IN 20 YEARS

"Electronic Witch"

The basic "Electronic Witch" unit, complete and ready to operate.

LOCATES, with greater depth penetration, exact position of buried pipe. . . . Traces further and more accurately.

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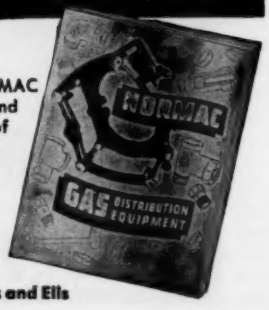

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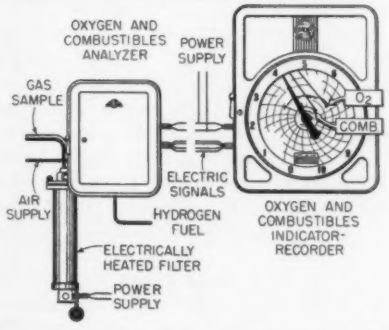
signal actuation. A range of nickel, tungsten, and platinum resistance temperature detectors is available, covering temperature of minus 200°C to plus 500°C (minus 328°F and plus 932°F). All except the platinum bulbs feature linearized chart scales. A full range of control forms, both electric and pneumatic, is available.

Null-Balance Recorder-Controllers. Fielden Instrument Div., Robertshaw-Fulton Controls Co., 2920 No. 4 St., Philadelphia 33, Pa.

Oxygen and combustibles analyzer

Operating information on combustion performance is provided through the use of this combination analyzer and the com-



pany reports that it can act as a safety guide to prevent the lighting off of unpurged, gas-fired combustion chambers. Analyses of $\%0_2$, an index of excess air, and % combustible, an index of fuel-air mixing performance, are said to be offered for the first time in a single unit. The gas analyzer and its recorder indicate or automatically control the necessary adjustments required to maintain combustion efficiency within combustion equipment limitations. Minimum range, 0-5%, maximum range, 0.25%. The unit uses compressed air and H_2 for catalytic combustion, and noble metal filaments with thermal conductivity compensators are part of null balance bridges. The analyzer is reportedly accurate within ±0.25% by volume of O_2 and combustibles contents in sample.

Bailey Oxygen and Combustibles Analyzer. Bailey Meter Co., 1050 Ivanhoe Rd., Cleveland 10.

Oxygen analyzer

A continuous specific oxygen analyzer designed for low range measurement of oxygen in gaseous streams, this unit features specific measurement of oxygen without interference by most other gaseous components, and offers reproductibility over extended periods. All parts which contact the gaseous sample or liquid stream are made of stainless steel or plastic. In the standard model, the light source, power switch and pump motor are explosion-proof, and all other electrical components are air purged. Available equipment includes a self-supporting panel, single point continuous indicator and recorder, circular chart recorder, flow chain cabinet with plexiglas window, and an explosion-proof circuit breaker and pump.

Davis Instruments Div., Davis Emergency Equipment Co., Newark, N. J.

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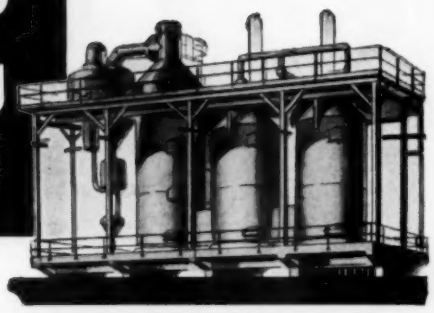
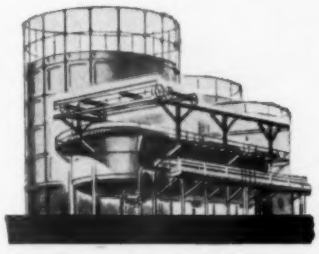
since 1902



means continuous service and profit to you



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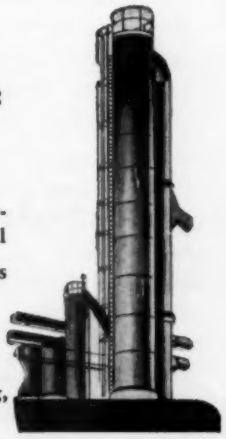

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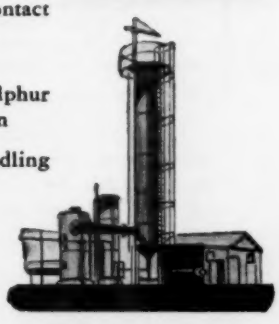
- Oil Scrubbing, Light Oil Recovery, Tar Handling and Other By-Product Methods
- Auxiliary LPG Systems
- Liquefaction, Storage and Regasification of Natural Gas



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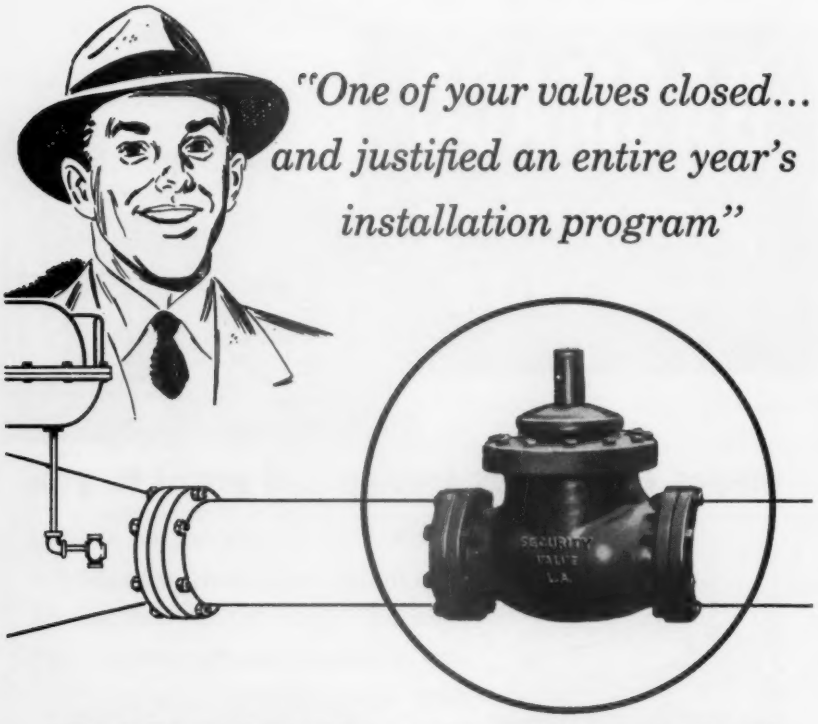

■ That's the experience of just one of the major gas companies and gas-using industries from coast to coast who have standardized on Security Automatic Shut-Off Valves. Because of their *absolute* protection against overpressuring, the operation of a single Security Valve can pay for a system-wide installation.

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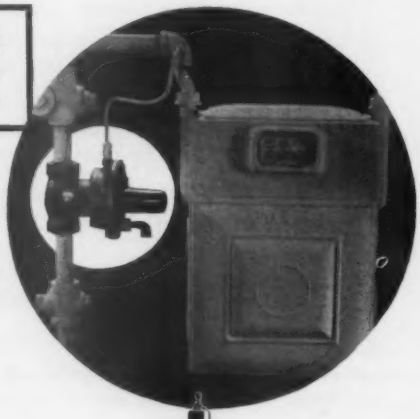
Security Automatic Shut-Off Valves range from ¾" for domestic lines (right) to large distribution line sizes (above).



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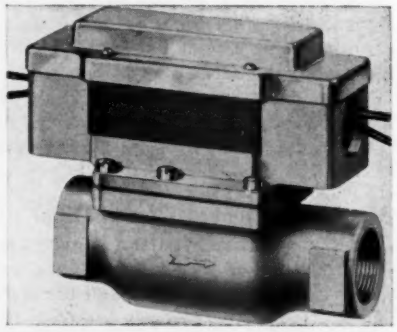
Control valve

A new main control valve using a rotor operating in a magnetic field instead of a solenoid, this control is offered in a low

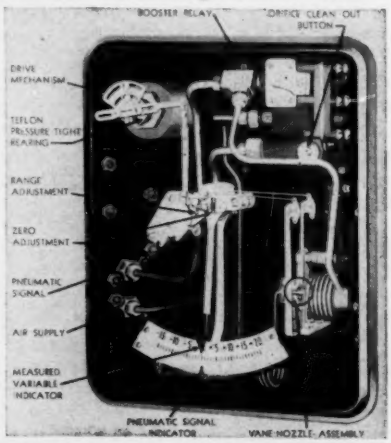


voltage model in ¾" size. It has a capacity of 170,000 Btu/hr with manufactured gas and 252,000 Btu/hr with natural gas. Characteristics of the valve, according to the manufacturer, are such that greatest force is exerted at the beginning of the stroke when the valve must open against gas pressure, resulting in the valve's having less tendency to stick. It closes against a synthetic rubber seat. The transformer is built into the control, and can be turned end for end to facilitate wiring. The transformer is replaceable. The valve body can be mounted in any position through 360° around the centerline of the valve.

Actrol Valve, Model MA5G1. Milwaukee Gas Specialty Co., Milwaukee, Wis.

Pneumatic transmitter

A pneumatic transmitter for telemetering and control systems, this unit can be used for transmitting measurements of



flow, level, pressure, temperature, draft, differential, and vacuum. The measuring element actuates the unit's micro-sensitive vane, nozzle, and booster assembly. Transmitted signals of 3-15 and 3-27 psig may actuate pneumatic receivers and controllers. The measured variable and pneumatic signal are indicated on a common scale for checking and comparison. Transmitting distances can be 1,000 ft to receivers, 400 ft to controllers. Accuracy is within ± ½% of measured range span, and air consumption is less than 0.15 cfm.

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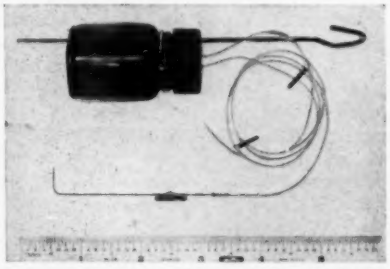
METERS

Meter pen

For use on recording instruments and meters, this meter pen is said to reduce re-inking practices and to record for periods



up to a year with only one filling. Pulsating flow, rapid pen movement and atmospheric fluctuations have no effect, the manufacturer reports, and the chances for errors through unrecorded intervals are eliminated. Non-clogging, made of stainless steel, the pens offer a continuous supply of ink that is assured by capillary feed upward through a flexible plastic tube connected to a ½ oz. reservoir. The reservoir, suspended inside the recorder case, reportedly protects the ink from dust and atmospheric contamination and holds up to a year's supply. Available in various types for all standard recording instruments, the pens may be mounted quickly on installed meters.

Canon Meter Pens. American Meter Co., Erie, Pa.

Aluminum gas meter

A lightweight die-cast aluminum gas meter with a rated capacity of 415 cf/hr, this new unit weighs only 20 lbs. as com-

pared with the manufacturer's cast iron meters of comparable capacity, which weigh 62 lbs. The new meter has a single sealing flange between cover and body, and its valve plate is completely enclosed within the case. It also features oil-impregnated powdered metal bearings. Measuring 14¾" high, 11⅛" wide and 9⅜" deep, the unit has 7" spud centers, roll type diaphragms and four chamber design D slide valves

with duplex tangent adjustment. Another feature of the meter is said to be its increased resistance to atmospheric corrosion.

Aluminum Gas Meter 415. Rockwell Mfg. Co., 400 No. Lexington Ave., Pittsburgh 8, Pa.

Aluminum meter

This meter is said to be an aluminum version of the manufacturer's standard No. 1 gas meter. Weighing 22 lbs. as compared with the standard meter, which weighs 45 lbs., the new meter has been designed to offer more ease in handling and setting, and greater resistance to weather and shock, the company reports. It has a pressure cast aluminum body; tested at 10 psi, it has a rated capacity of 5 psi. Available with offset swivels for 10 light meter bar installations, the meter has a maximum capacity of 275 cf/hr, at ½" pressure drop with 0.60 specific gravity gas.

Aluminum Meter. Rockwell Mfg. Co., 400 No. Lexington Ave., Pittsburgh 8, Pa.

Domestic meter

With a rated capacity of 225 cu ft/hr of 0.6 sp. gr. gas at ½" w.c. differential, and working pressure of 5 psi, this new meter is said by the company to meet the need for larger capacity, light weight and low cost in positive displacement gas meters for domestic service. Features of the new meter include the use of pressure die-cast aluminum alloy construction to reduce weight while providing high-impact resistance. Interior construction includes parts changeability; permanently self-lubricated porous bronze bearings; choice of synthetic or leather diaphragms and new grommet-type bushings for positive leak protection. The meter's index box is of clear, strong plastic providing resistance to injury and ease of reading.

5B-225 Aluminumcase Meter. American Meter Co., Erie, Pa.

Aluminum case meter

Approximately the size of the manufacturer's Standard 1A model, this new meter reportedly was designed to meet demands

for increased domestic loads. The new unit has a cast aluminum case and weighs 13 lbs. It features a capacity of 240 cubic feet per hour—½ inch differential with 0.60 specific gravity gas. The case size and connections are identical to the 1A meter and, the manufacturer states, most parts are interchangeable.

Sprague 240 Meter. The Sprague Meter Co., Bridgeport, Conn.

MISCELLANEOUS

Pilot

Called the target pilot, this new pilot, introduced by the manufacturer for use in gas operated appliances, reportedly was developed to overcome the susceptibility of pilots to linting and clogging at the primary air intake. According to the company, the new pilot does away with such air intakes and will maintain a steady blue flame for

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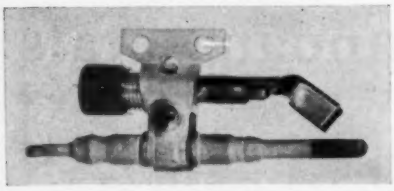
proper safety control operation. Fabricated from stainless steel, its construction is said to resist corrosion.



Target Pilot No. 2B. Robertshaw-Fulton Controls Co., Thermostat Div., Youngwood, Pa.

Pipe finder

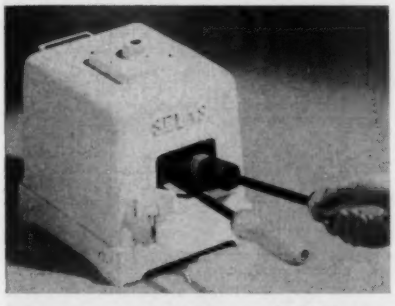
This new electronic instrument for locating and tracing buried pipes, conduits and metal objects, features a new electronic

circuit. The instrument cabinets are of moulded fiberglass said to be impervious to water, and will not scratch, stain, splinter or bend. The new circuit is insensitive to temperature changes and the shock and vibration of field use. The receiver selectivity and operational frequency make the new unit less sensitive to all types of outside interference, the company reports, particularly that associated with neon signs and overhead power lines.

Electronic Witch M-Scope. Fisher Research Laboratory, Inc., Palo Alto, Calif.

Soldering furnace

This gas-fired soldering furnace, using a radiant burner, is said to be capable of heating within 8 minutes, two 4-lb. irons



from room temperature to 900° F, or a single 4-lb. iron to 1,200° F, with a heat input of 9,100 Btu/hr. The manufacturer reports that the burner is located so that mechanical shock and flux corrosion damages are kept to a minimum, and that the refractory hearth may be easily removed and cleaned. Heating is said to be done without flame impingement, yet the soldering copper is surrounded by fully-burned gases which virtually eliminate oxidation and burning of the copper, enabling it to

(Continued on page 176)

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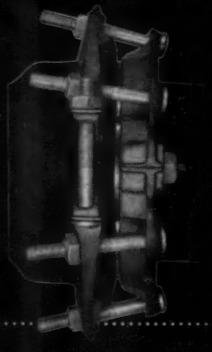

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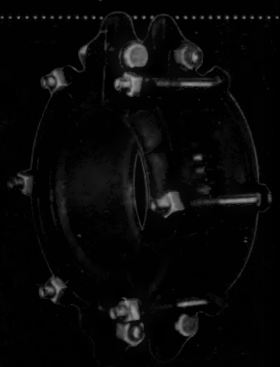

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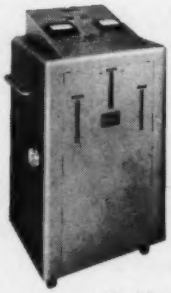

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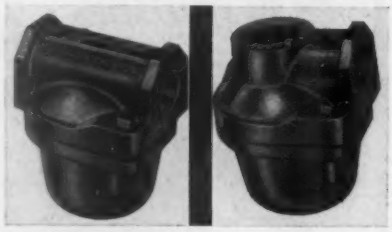
retain a bright, tinned working surface.

Selas Soldering Furnace. Selas Corporation of America, Erie Ave. and D St., Philadelphia 34, Pa.

Dust trap

An all metal dust trap has been introduced by the manufacturer featuring a filtering element consisting of a porous bronze casting. Each element is reportedly tested for controlled porosity, which will not change up to 15 psi differential pressure. The filter operates on the following principles: velocity; centrifugal force which will remove up to 70% of the dust; and the filtering element, which removes dust particles down to 10 microns in size. The units can be supplied in ¾" and 1" female pipe sizes and in straight or angle connections. The bowl and element can be removed for



inspection or replacement without disturbing the piping, the company reports.

All Metal Dust Trap. Sprague Meter Co., Bridgeport 4, Conn.

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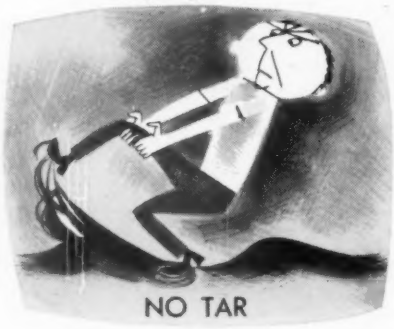
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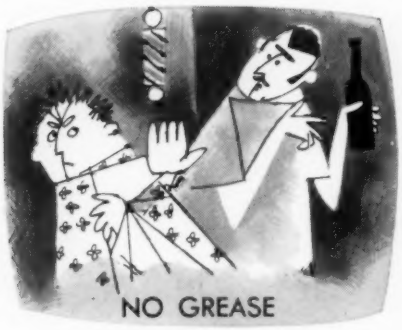
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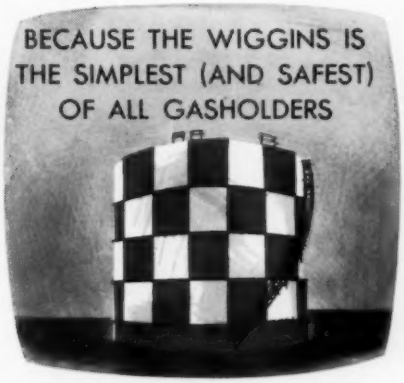

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